AN INVESTIGATION OF SOME OF THE PHYSICAL PHENOMENA OF THE

ELECTRIC DISCHARGE IN GASES

Approved:

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Dean of the Graduate School

AN INVESTIGATION OF SOME OF THE PHYSICAL PHENOMENA OF THE ELECTRIC DISCHARGE IN GASES

DISSERTATION

Presented to the Faculty of the Graduate School of
The University of Texas in Partial Fulfillment
of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

By

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Preface

The work presented here is part of a long term research program carried out by the Bureau of Industrial Chemistry of the University of Texas, under the direction of Dr. E. P. Schoch. The writer thanks Dr. Schoch for his able and patient direction of this investigation and for the sharing of his vast fund of experience. He also thanks Dr. H. A. Holcomb who was his co-worker throughout the investigation and Dr. A. S. Kasperik who was a co-worker during part of the investigation. Thanks are due also to Messrs. W. L. Benson, J. L. McGee, P. K. Pruett, and J. W. Roper for help in the construction of the apparatus; to Dr. J. M. Kuehne, Mr. R. P. Lightfoot, and Dr. Eugene Schoch, Jr., for loan of photographic equipment; to Miss Erin Colleen Moore and Dr. W. L. Ray for analytical work performed in connection with this work; and to the following members of the staff of the Bureau as well as others already mentioned for many instances of cooperation when equipment had to be shared by two or more project groups; Messrs. A. J. Burks, E. J. Claassen, A. M. Cuellar, Drs. W. B. Howard, K. I. Glass, Max Samfield, and Messrs. J. W. Sheehan and J. L. Weeks.

July, 1946

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INTRODUCTION

The study reported here was undertaken for the purpose of securing a better understanding of the fundamental factors affecting the action of the electric discharge in gases, and for the purpose of attempting to obtain a milder discharge which might serve to produce more closely controlled chemical effects. While in a general sense it is based on the whole seventeen years of research on this subject made by the Bureau of Industrial Chemistry, it is more particularly a direct outgrowth of the work done during the three or four years just prior to its inception in 1944. While many new facts have come to light during this investigation, the work reported here should be considered only as one phase of the work that must be done in order to find ways of controlling the action of the discharge even more advantageously than has been done until now.

The immediate background for this phase of the work is set forth below, but for a broad background for the understanding of the behavior of the electric discharge in gases, the reader should refer to the numerous theses and dissertations written on the subject under the supervision of Dr. Schoch. The more essential works are listed separately in the bibliography.

During the summer and fall of 1943, Howard and Kasperik[1] performed tests with the electric discharge using as one electrode a rotating cylinder about four inches long and ten and five-eighths inches in diameter and

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1 Howard, W. B. and Kasperik, A. S., Unpublished Reports, Bureau of Industrial Chemistry, University of Texas, 1943.

as the other electrode a wheel about two and five-eighths of an inch wide and twenty inches in diameter, and constructed in such a way as to act as the impeller of a blower. They found that the speed of the blower wheel was an important factor in determining the electrical characteristics of the discharge. These tests and a desire to improve the efficiency of the electric discharge led to tests on electrode arrangements other than the one already mentioned. In one set of tests the discharge was initiated between the blower electrode and a rotor two inches in diameter, and the main discharge took place between the blower and a screen which was curved around the blower. Near the small rotor the distance between the screen and the blower was about two inches and this separation increased gradually to about six inches. From an observation of the wear on the screen it was concluded that regardless of the blower speed, the most intense discharge always took place on a part of the screen about six inches above the small rotor. In view of the experiments reported here, this conclusion may be amended to state that for a certain combination of current, blower speed, and electrode arrangement, the greatest amount of discharge will take place in certain regions, but that these variables can be changed so as to move this zone from one part of the screen to another. Methods were sought by which greater amounts of gas could be introduced into the region of most intense discharge and also by which the two variables of gas rate and electrode speed could be separated. These efforts led to a design of a chamber by Holcomb, Sheehan, and Weeks[2] in which controlled amounts of gas could be introduced

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[2] Holcomb, H. A., Sheehan, J. W., and Weeks, J. L., Unpublished Design Drawings, Bureau of Industrial Chemistry, University of Texas, 1944.

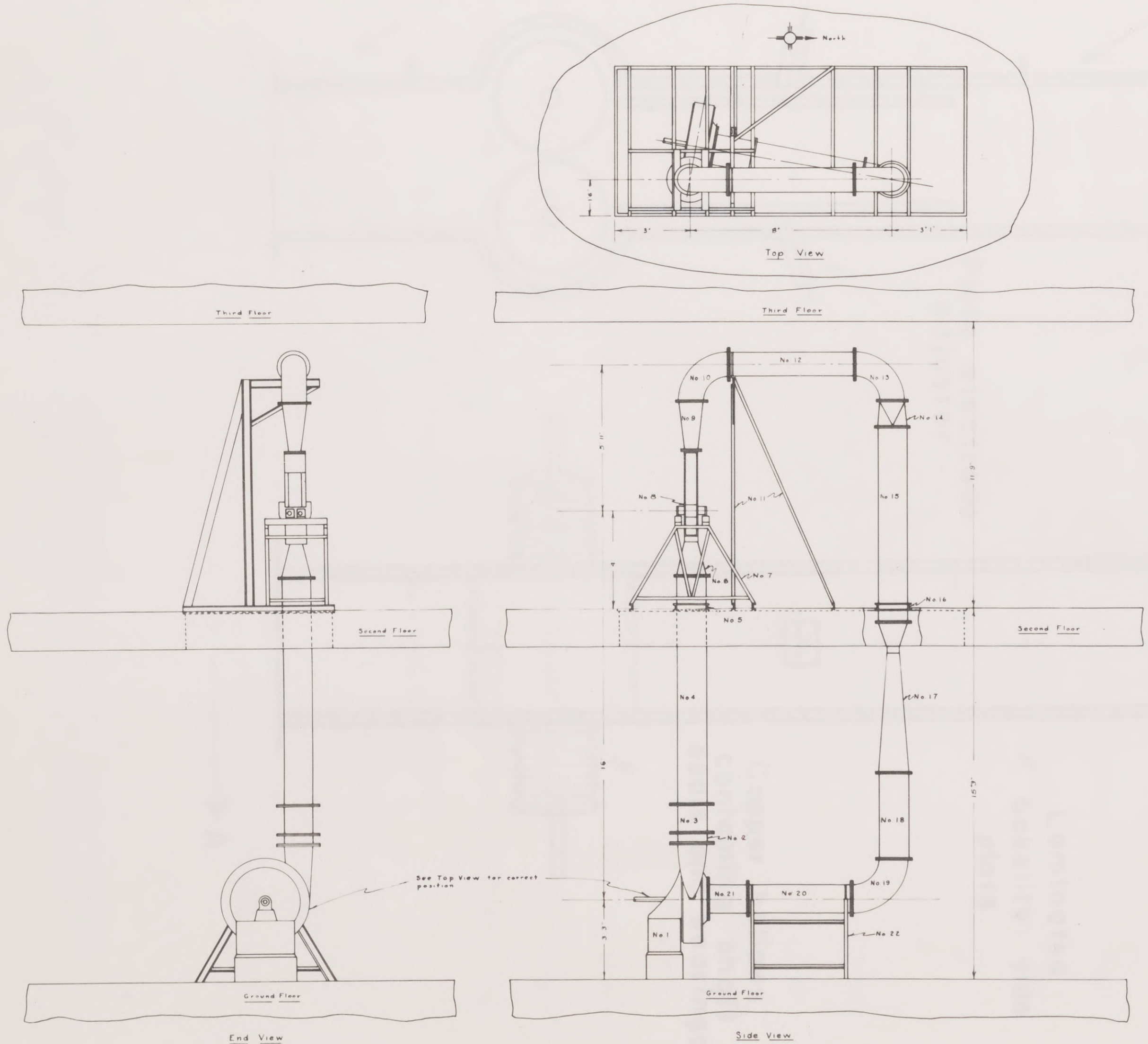
into the three regions of the discharge: (a) the initiating region, (b) the region of most intense discharge, and (c) a third region beyond (b) where the intensity was relatively small. This apparatus was not constructed, however, because it was decided that although it did have the advantage of allowing the introduction of gas in controlled amounts into different parts of the discharge, it had the disadvantage that the sideways flaring of the discharge plus the varying distance between the electrodes complicated an already difficult analysis of the problem. In the hope of obtaining a chamber with more regular geometric dimensions, the discharge chamber used in this investigation was designed and built. A description of the original chamber and related apparatus will be found immediately following this introduction. The changes found necessary, however, will be described later in chronological order.

DESCRIPTION OF APPARATUS

The discharge apparatus as a whole consists of the discharge chamber proper, a centrifugal blower, a venturi tube and accessories such as motors, manometers, electrical instruments and instrument transformers. The blower and the motor to drive it were mounted on a concrete base on the first floor of the Chemical Engineering Building with the outlet pipe of the blower placed vertically so that the discharge chamber could be mounted directly above it. The latter was installed on the second floor and had its inlet and outlet in a vertical line with the blower outlet. The relative positions of blower, chamber and venturi tube are shown in Figure 1. The system is supplied with inlet and outlet lines for feed and product gases, respectively.

Discharge Chamber: The first discharge chamber used in this investigation consisted essentially of a tube with four electrodes. Two of these were rotors with parallel axes, the others were two parallel plates. Their arrangement is shown in Figure 2. These two pairs of electrodes were mounted in such a way that they could be insulated electrically from one another, but the low potential plate was at ground potential and the low potential rotor was, at first, connected to ground through its bearing holder. Later this rotor was also insulated from the plate.

The bearing holders for the rotors were attached to the bakelite sides of the chamber by means of copper bellows so as to permit the adjustment of the rotor-to-rotor distance. The external ends of the bearing holders were mounted on adjustable brackets. The high potential rotor could be adjusted only when the discharge was off, but the other one could be adjusted at any



No	Description	Dr No
1	Blower	Allen Billmyre 10-3M-305
2	Slide Valve	
3	Rubber Connecter	
4	14" Pipe	
5	4" Channel Iron Support	
6	Transition Piece	
7	Bearing Holder Support	
8	Reaction Chamber	
9	Transition Piece	
10	Elbow	
11	Pipe Support	
12	12" Square Pipe	
13	Elbow	
14	Transition Piece	
15	14" Pipe	
16	4" Channel Iron Support	
17	Venturi	
18	14" Pipe	
19	Elbow	
20	14" Pipe	
21	Rubber Connecter	
22	Pipe Support	

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1944 Reaction Chamber No 1
Unit Assembly

Drawn	Date		
W A K	9/18/44		No 1

FIGURE NO. 1

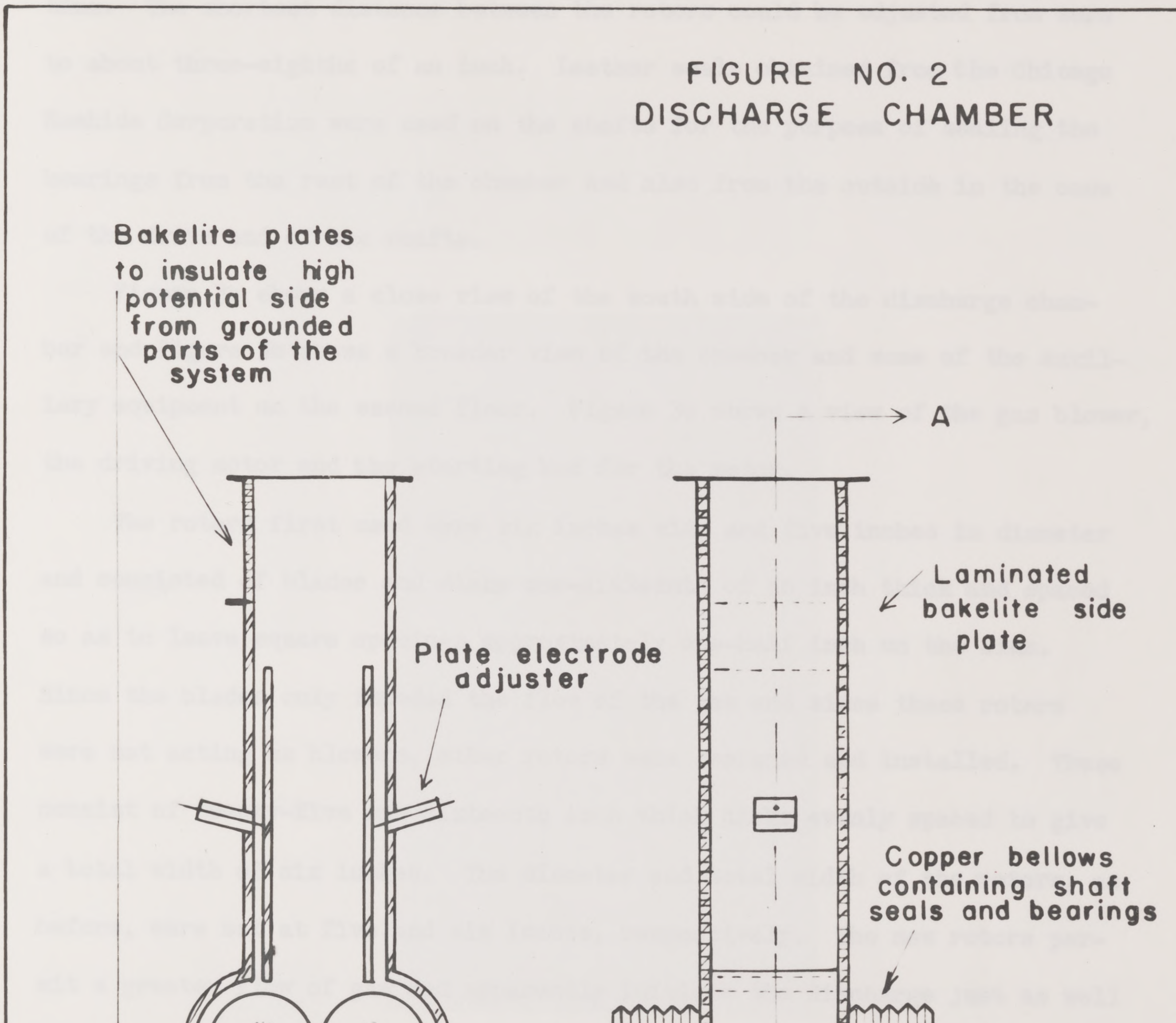
FIGURE NO. 2
DISCHARGE CHAMBER
Bakelite plates to insulate high potential side from grounded parts of the system
Plate electrode adjuster
Laminated bakelite side plate
Copper bellows containing shaft seals and bearings
A
A

time. The shortest distance between the rotors could be adjusted from zero to about three-eighths of an inch. Leather seals obtained from the Chicago Rawhide Corporation were used on the shafts for the purpose of sealing the bearings from the rest of the chamber and also from the outside in the case of the drive end of the shafts.

Figure 3a shows a close view of the south side of the discharge chamber and Figure 3b shows a broader view of the chamber and some of the auxiliary equipment on the second floor. Figure 3c shows a view of the gas blower, the driving motor and the starting box for the motor.

The rotors first used were six inches wide and five inches in diameter and consisted of blades and disks one-sixteenth of an inch thick and spaced so as to leave square openings approximately one-half inch on the side. Since the blades only impeded the flow of the gas and since these rotors were not acting as blowers, other rotors were designed and installed. These consist of twenty-five one-sixteenth inch thick disks evenly spaced to give a total width of six inches. The diameter and total width of the rotors, as before, were set at five and six inches, respectively. The new rotors permit a greater flow of gas and apparently initiate the discharge just as well as the blade and disk type. The first electrode plates used were six inches wide, fifteen inches long and one-half inch thick. The distance between the plates could be adjusted from about two inches to five inches.

Centrifugal Gas Booster: The gas is circulated in the system by an Allen Billmyre Centrifugal Gas Booster Model 10-SM-365 driven by a forty horsepower electric motor. The booster has the following ratings[3] when

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[3] Gordon S. Williams, Allen Billmyre Company, Private Communication, 1944. (Performance Curve 10-SM-365, Allen Billmyre Company, Mamaroneck, N. Y.)

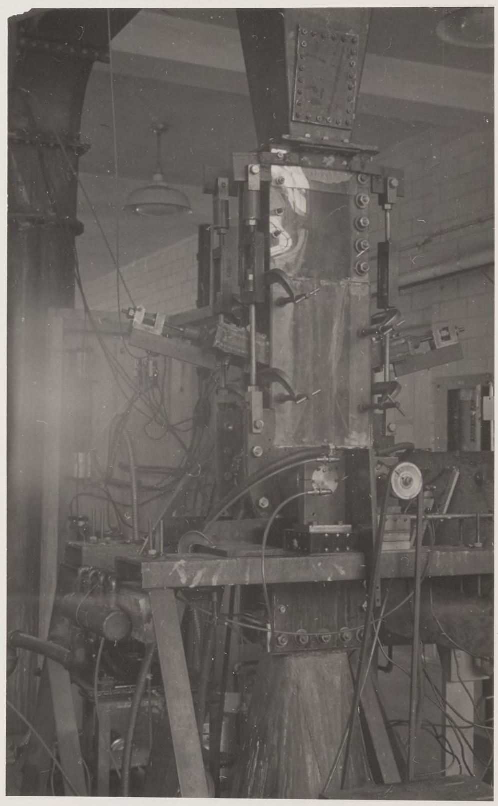

Figure 3a

Close View of Discharge Chamber

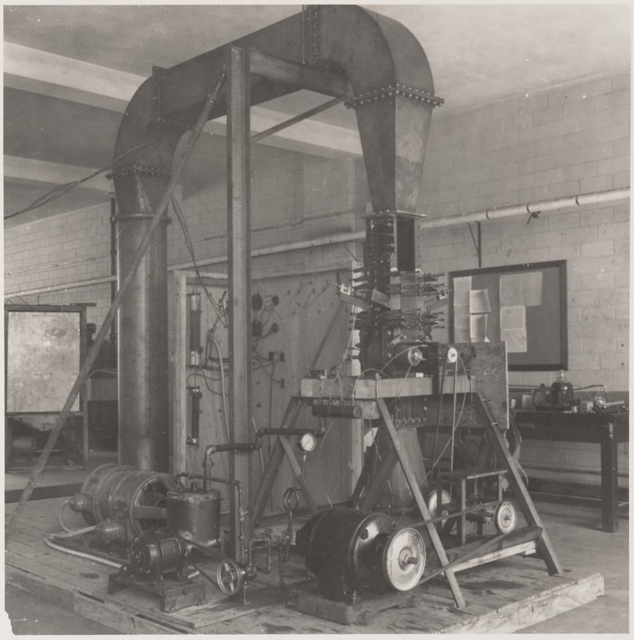

Figure 3b

Discharge Chamber and Auxiliary Apparatus

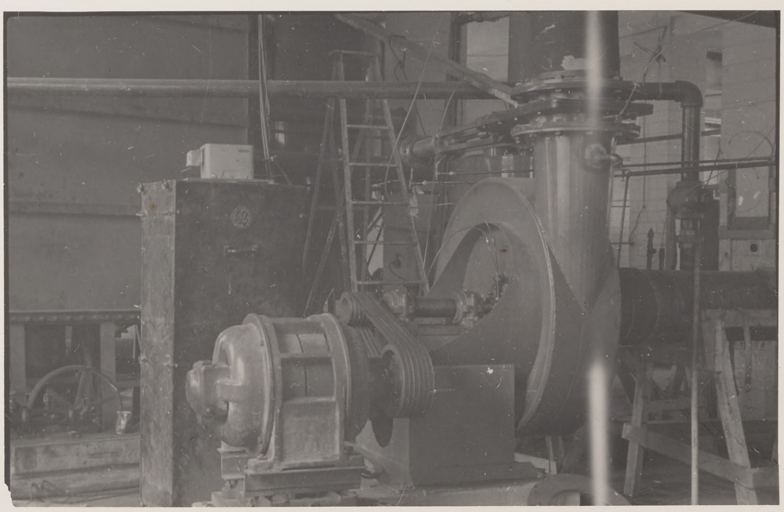

Figure 3c

Centrifugal Gas Booster

operated on air at an inlet pressure of 29.92 "Hg absolute and an inlet temperature of 68°F: When the speed is 4320 r.p.m. the outlet pressure stays between 1.6 and 1.7 pounds per square inch while the output varies from zero to 4000 cubic feet per minute. At a speed of 3500 r.p.m. the outlet pressure stays between 1.0 and 1.1 pounds per square inch while the output varies from zero to 4600 c.f.m. The power varies linearly with output as follows:

Speed, r.p.m.	Output, c.f.m.	Power consumption, h.p.
4320	1000	32.
4320	4000	53.5
3500	1000	15.5
3500	4000	29.

The seal around the shaft of the booster originally consisted only of graphite covered asbestos rope wrapped around the shaft and contained in a suitable case. Since this did not form an absolutely gas tight seal, and since it was anticipated that for some tests the entire system would need to be gas tight, this seal was replaced by a bellows type shaft seal obtained from the Crane Packing Company.[4] A slide type blast gate valve also purchased from the Allen Billmyre Company is attached to the outlet of the blower. In order to facilitate control of the booster, start and stop switches for the motor were installed on both the first and second floors and provisions were made for remote control of the valve. The valve stem is attached to a piston which can be made to move in either direction by applying water pressure at the proper end of the enclosing cylinder. The valves to control the flow of water were installed on the control table in the second floor of

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[4] Mr. V. E. Vorhees, Crane Packing Company, Private Communication, August, 1945. (Figure 1, Type 2, Drawing F-SD-1033-1, Crane Packing Company, Chicago, Illinois, February, 1945.)

the building.

Electrical Circuit: In the case of tests with alternating current, the circuit current was kept sinusoidal (60 c.p.s.) by means of the T-circuit described by Steinmetz[5] and used by Howard[6] and Kasperik.[7]

Venturi Tube: The venturi tube was designed to be attached to a fourteen inch thin wall pipe and to give a difference of pressure of about ten inches of water between upstream and throat taps when meeting the following or equivalent conditions:

Gas rate: 80 cu.ft./sec.

Mol. wt. of gas mixture: 15

Temperature of gas: 130°F.

Upstream pressure: 29.92 in. Hg absolute.

Since it had been observed that the venturi tubes made for the pilot plant described by Kasperik[8] were not made accurately according to specifications, it was decided to calculate the throat diameter only approximately and to calibrate the tube before using it. For design purposes the discharge coefficient was taken as unity and the calculations were based on the equation

$$V_2^2 - V_1^2 = 2g\Delta H,$$

where

V_2 = gas velocity at the throat, ft/sec.

V_1 = gas velocity at the upstream tap, ft/sec.

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5 Steinmetz, C. P., Theory and Calculation of Electric Circuits, McGraw Hill Book Company, New York, 1917, Ch. 14.

6 Howard, W. B., Dissertation, The University of Texas, 1943.

7 Kasperik, A. S., Dissertation, The University of Texas, 1943.

8 Kasperik, A. S., Ibid.

g = gravitational constant = 32 ft/sec.^{2}

ΔH = difference of pressure between taps, expressed in terms of feet of the fluid flowing in the tube.

This resulted in a throat diameter of 6.78 inches. The vertex angle for the converging section was set at 35° and for the diverging section at 7°. The length of the throat was set at three inches.

The tube was calibrated against a Thomas meter[9] using both air and natural gas. A thermopile borrowed from the Department of Chemical Engineering was used to determine the increase in temperature brought about by the power added in the meter. A calibration curve for this thermopile is part of the Chemical Engineering Laboratory Collection in the Chemical Engineering Building.[10]

Tables 1, 2, and 3 give the calibration data and results. The calibration with natural gas was included as an extra check. However, the results of the air calibration and those of calculations based on the dimensions of the tube checked better with each other than did the natural gas results with either of the others.

Perry[11] gives the following equation:

$$W = q_1 \rho_1 = CYA_2 \sqrt{\frac{2g_2 \rho_1^2 \Delta H}{1 - B^4}}$$

where

w = weight rate of discharge, lb/sec.

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[9] Rhodes, T. J., Industrial Instruments for Measurement and Control, McGraw Hill Book Company, New York, 1941, p. 315.

[10] Department of Chemical Engineering, University of Texas, E.M.F. vs. Temperature Difference Curve - Exp. 5, 1943.

[11] Perry, John H., Editor, Chemical Engineer's Handbook, 2nd. Edition, McGraw Hill Book Company, 1942, p. 847.

q_1 = volumetric rate of discharge, cu.ft/sec.

ρ_1 = density at upstream pressure and temperature.

C = coefficient of discharge.

Y = expansion factor.

A_2 = cross sectional area of discharge opening, sq.ft.

g_2 = local acceleration due to gravity.

B = throat diameter/pipe diameter.

ΔH = orifice differential, ft. of fluid of upstream density.

Assuming:

Throat diameter = 6.78"

A_2 = 0.251 sq.ft.

g_2 = 32.16

Y = 0.98

C = 0.96

one obtains $q = 1.938 \sqrt{\Delta H}$, and if ΔH is expressed in inches of water and one assumes that upstream pressure is 750 mm Hg, absolute,

$$q = 3.72 \sqrt{\frac{"H_2O(T^oR)}{M}} = 5.0 \sqrt{\frac{"H_2O(T^oK)}{M}}$$

where M = molecular weight. The equation resulting from the experimental data on air is

$$q/77 = \sqrt{\Delta H}/40 \qquad \text{or } q = 1.925 \sqrt{\Delta H}$$

(Most of the points for gas did not fall exactly on the line defined by this equation.) Since it is this equation that is used later it is converted here to some of the more useful forms:

$$q = 1.925 \sqrt{\frac{"H_2O(62.3)}{12\,(\rho_1)}} = 4.39 \sqrt{\frac{"H_2O}{\rho_1}}$$

or again assuming that the upstream pressure will be 750 mm. Hg:

$$q = 3.695 \sqrt{\frac{''H_2O(T^oR)}{M}} = 4.96 \sqrt{\frac{''H_2O(T^oK)}{M}}$$

Since the difference between the experimental and calculated values turned out to be so small, the equation $q = 5.0 \sqrt{\frac{''H_2O(T^oK)}{M}}$ was taken as correct.

TABLE I

Composition, molecular weight, and specific heat of natural gas
(Basis: 100 mols)

Gas	Mols[12]	Mol. wt.	Wt.	Sp. Heat	Heat
CO_2	0.60	44	26.4	0.21[13]	5.54
CH_4	89.72	16	1435.5	0.53[14]	760.82
C_2H_6	5.48	30	164.4	0.415[14]	68.23
C_3H_8	2.21	44	97.2	0.376[14]	36.55
C_4H_{10}	1.02	58	59.2	0.357[14]	21.13
C_5H_{12}	0.44	72	31.7	0.347[14]	11.00
C_6H_{14}	0.27	86	23.2	0.339[14]	7.86
C_7H_{16}	0.18	100	18.0	0.335[14]	6.03
N_2	0.08	28	2.2	0.250[13]	0.55
	100.00		1857.8		917.71

917.71/1857.8 = .494 specific heat of gas

mol. wt. = 18.58

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[12] Claassen, E. J., Thesis, The University of Texas, 1944.

[13] McAdams, W. H., Heat Transmission, Second Edition, McGraw Hill Book Company, 1942.

[14] Natural Gasoline Association of America, Technical Manual, Tulsa, Oklahoma, 1941.

TABLE II

Calibration Data with Natural Gas

Gas temp. ^{o}C	Gas temp. ^{o}K	Density lb/cu.ft.	ΔH "H_2O	$\Delta H'$ ft.gas	Power rate KW (Thomas meter)	Thermo-couple reading mv	ΔT ^{o}F	lb.gas per hour	cu. ft. gas per second	$\sqrt{\Delta H'}$
42.0	315.1	0.0442	23.10	2710	2.124	0.066	0.54	27,190	171.	52.1
51.0	324.1	0.0430	18.80	2270	2.124	0.110	0.89	16,500	107.	47.2
55.3	328.4	0.0424	14.70	1800	2.120	0.140	1.16	12,630	83.	42.5
58.5	331.6	0.0421	10.70	1320	2.120	0.160	1.32	11,100	73.	36.4
60.5	333.6	0.0418	6.65	814	2.110	0.195	1.61	9,060	60.	28.6
61.8	334.9	0.0416	3.60	449	2.110	0.250	2.07	7,050	47.1	21.2
61.3	334.4	0.0417	1.80	224	2.110	0.335	2.77	5,270	35.1	15.0
67.5	340.6	0.0409	19.40	2460	2.120	0.120	0.98	14,950	101.5	54.2

TABLE III

Calibration Data with Air

Wet bulb temp. ^{o}F	Dry bulb temp. ^{o}F	Sp.heat (15)	Density lb/cu.ft.	ΔH "H_2O	Power rate KW (Thomas meter)	Thermo-couple reading mv	ΔT ^{o}F	lb.air hr.	Air rate cu.ft/sec.	$\Delta H'$ ft. of air	$\sqrt{\Delta H'}$
63.2	82.6	0.242	0.0725	1.65	2.39	0.785	6.65	5,060	19.4	118	10.89
60.0	75.0	0.242	0.073	3.15	2.38	0.560	4.69	7,150	27.2	224	14.99
60.5	76.6	0.242	0.073	5.05	2.40	0.437	3.62	9,350	35.6	359	18.98
62.0	79.0	0.242	0.0725	6.95	2.39	0.375	3.10	10,870	41.7	498	22.30
68.	97.0	0.242	0.071	8.85	2.36	0.325	2.69	12,400	48.5	647	25.40
68.	97.0	0.242	0.071	11.60	2.36	0.286	2.36	14,100	55.2	847	29.1
68.	97.0	0.242	0.071	20.55	2.38	0.235	1.95	17,200	67.3	1400	37.2
68.	97.0	0.242	0.071	23.0	2.34	0.224	1.86	17,750	69.5	1680	41.0
68.	97.0	0.242	0.071	23.9	2.36	0.215	1.78	18,700	73.1	1750	41.8

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15 Badger, W. L. and McCabe, W. L., Elements of Chemical Engineering, Second Edition, 1936, McGraw Hill Book Company, New York, Figure 114.

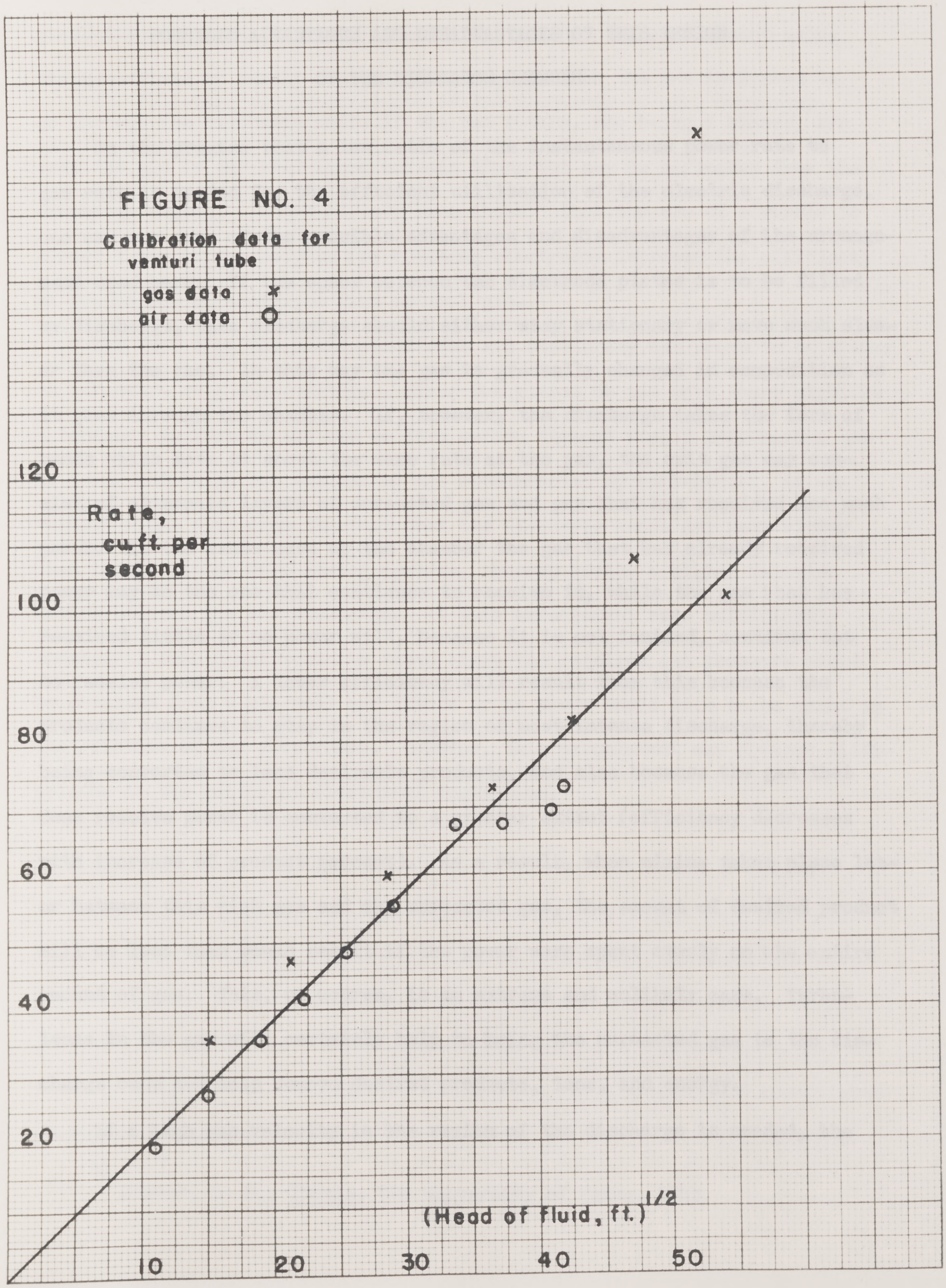

FIGURE NO. 4
Calibration data for venturi tube
gas data x
air data O
Rate, cu.ft. per second
120
100
80
60
40
20
10
20
30
40
50
(Head of fluid, ft.)$^{1/2}$

POSSIBLE ADVANTAGES AND DISADVANTAGES OF THIS DESIGN OF THE DISCHARGE CHAMBER

On the premise that a low ratio of the instantaneous power rate to gas rate is needed for the efficient utilization of the electric discharge, one can see some of the possible advantages and disadvantages of the arrangement used here. If the space between the electrode plates is to be filled by discharge, this discharge should either stay stationary or move much slower than the gas. In this way the gas is gradually changed in composition as it goes through the chamber. If, however, the discharge takes the form of bands which move at about the same rate as the gas, the exit gas may consist of alternate layers of unreacted gas and gas that has received too much power. As the bands move up the chamber the gas that has already received power may be the one that continues to receive it, while the gas that has received little or no power will, because it is not ionized, continue not to receive power. A lower efficiency will result from this because the products continue to stay in the region of most intense discharge, thereby being converted to less desirable products, and also because the gas that does receive power is converted to a greater extent (efficiency decreases with increase of product percent). As a result, when mixing takes place later between this rich gas and the unreacted gas, the amount of desired product will be less than would result if the power were spent evenly on the entire amount of gas. This, of course, is an extreme and unlikely case. Turbulence in the gas will certainly help to bring the unreacted gas to the discharge band and help remove desired products, ions, and energy.

If a high gas velocity in the region of the discharge is needed, the present arrangement can bring it about better than the arrangement using the unconfined or partly confined discharge because the gas is forced to go through the discharge while if the two rotors, one being a blower, are used the gas is directed along certain lines but may be deflected from the discharge region. It has already been shown[16] that the use of a nozzle to direct a gas stream between two rotating electrodes improved the efficiency of production of acetylene from natural gas.

The fact that the plate electrodes are stationary can prove to be either an advantage or a disadvantage. Since the plates do not move there might be a tendency to form an arc and to form carbon "trees" when a hydrocarbon gas is used, but these two tendencies are counteracted by turbulence. An advantage might come from the fact that the discharge bands may move slower than if the plates were moving upwards, thereby giving a higher relative motion between gas and discharge. If this arrangement were sufficiently successful some power would be saved since the required gas pressure might be obtained from a gas well and little or no power would have to be spent in the rotation of any electrodes. However, this arrangement may present difficulties in the matter of electrical insulation.

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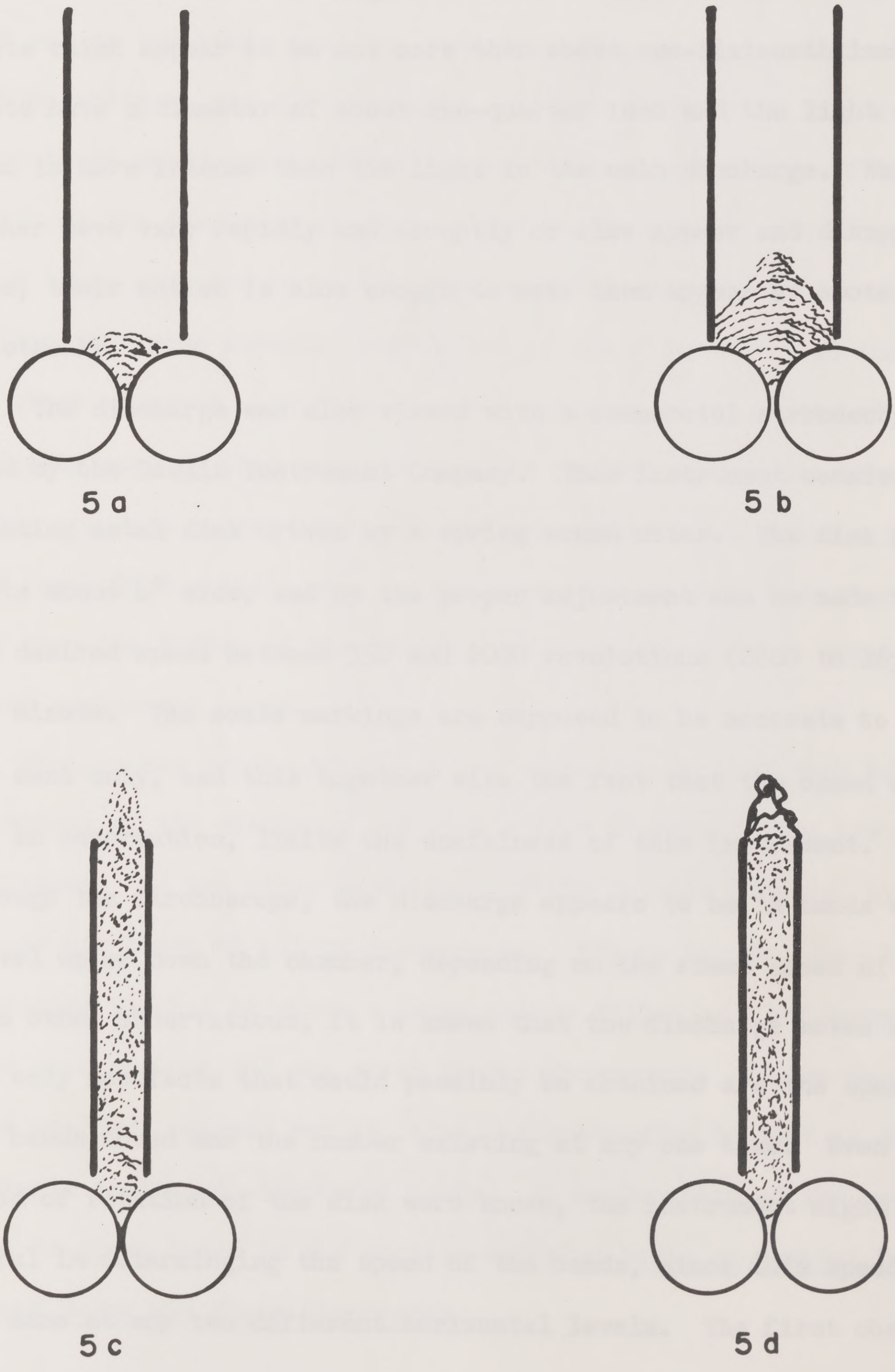
16 Montes, G. E., Thesis, The University of Texas, 1942.

DESCRIPTION OF THE DISCHARGE

The following is a description of the discharge in air, beginning with the description of its appearance to the unaided eye. When the rotor electrodes consist of disks only and the discharge current is 6.1 amperes a.c., the appearance of the discharge changes with voltage (rotor-to-rotor separation), gas velocity, and electrode plate separation. Starting with the point of nearest approach of the rotors (or approximately 1/4" above this point), and continuing on upwards the space between the rotors is filled by a light purple glow varying in intensity with time at any one point and varying across the face of the rotors or depth of the chamber at any one time. With a low gas velocity this glowing region takes on approximately the shape shown in Figure 5a. In this case as well as in the cases represented by Figures 5b and 5c, the discharge seen from the side, appears to consist of many small paths. Whenever the voltage and gas velocity are sufficiently high, a discharge also appears between the plate electrodes. Figure 5b shows the appearance in this case. With a sufficiently high gas velocity and voltage and a sufficiently small plate separation, the whole space between the plates fills with discharge and the discharge will even extend beyond the ends of the plates to a distance of twelve to fifteen inches. Figure 5c shows the appearance in this case. With this same plate spacing (app.2") and a low gas rate (Run 41, Table VII) the discharge goes beyond the ends of the fifteen-inch plates, but no longer continues to appear diffuse beyond the plates. Instead the plates are connected by two or three bright, concentrated streaks of circular cross section and approximately one-half inch in diameter. This condition is accompanied by relatively

FIGURE NO. 5



low discharge potential and is probably a true arc path. In all the cases cited above the discharge appears to originate from only a limited number of the rotor disks at any one time (8 to 12 disks) although not from the same ones all the time. On the plate electrodes the discharge streaks originate or terminate on a large number of circular or almost circular bright spots which appear to be not more than about one-sixteenth inch thick. These spots have a diameter of about one-quarter inch and the light coming from them is more intense than the light in the main discharge. While these spots either move very rapidly and abruptly or else appear and disappear at a fast rate, their motion is slow enough to make them appear as spots rather than as streaks.

The discharge was also viewed with a commercial stroboscope (Strobomeca) sold by the Boulin Instrument Company. This instrument consists of a thin rotating metal disk driven by a spring wound motor. The disk has eight radial slits about 4^{o} wide, and by the proper adjustment can be made to rotate at the desired speed between 350 and 2000 revolutions (2800 to 16,000 openings) per minute. The scale markings are supposed to be accurate to within ten per cent only, and this together with the fact that the speed changes during an observation, limits the usefulness of this instrument. When viewed through the stroboscope, the discharge appears to be in bands which seem to travel up or down the chamber, depending on the exact speed of the disk. From other observations, it is known that the discharge moves upwards; so the only new facts that could possibly be obtained are the speed at which the bands moved and the number existing at any one time. Even if the exact speed of rotation of the disk were known, the instrument might not be very useful in determinging the speed of the bands, since this speed may not be the same at any two different horizontal levels. The first observations always showed three light bands coexisting regardless of the value of the independent variables. It was found, however, that during certain parts of the cycle of rotation one of the slits and parts of two adjacent ones would be in front of the eyepiece. A light shield was installed so as to permit vision through only one slit at a time, and with this new arrangement one or two bands could be seen depending on the conditions of gas velocity, voltage, and plate spacing. If the plates were two or three inches apart there would appear to be two bands at opposite ends of the active length of the discharge chamber or one in the middle. In those cases in which there appeared to be two coexistent bands, one could not be sure whether they were actually coexistent or one disappeared at the time that the other appeared. In view of other evidence to be presented later, it is fairly certain that only one band is present at any one time. If the plates are five inches apart and the gas velocity and voltage are not very high (app. 2500 volts), none of the bands travel more than four to six inches from the bottom of the plates. In these cases there appears to be two almost coalescent bands.

Photographs of the discharge are revealing in that they help to "stop" the motion of the discharge and give a view of some of the instantaneous conditions. On the other hand, many of the details observed by the unaided eye are not shown at all by photographs. Figure 6a, for example, is very misleading in that it shows a large volume filled by glow whereas other evidence goes against the one given by the photograph. Figure 6b shows that there are dark spaces, yet it, also, is misleading in that it shows three seemingly coexistent discharge bands. An explanation of the cause of this error is given later in the section entitled <u>Tests on Current Distribution Between Rotor and Plate Electrodes</u>.

Figure 6a

Picture of Discharge taken with Focal
Plane Shutter Camera.
Scanning of the Object was from
Left to Right.

The remarks made here on the appearance of the discharge have no chronological bearing to other experiments reported. They are the result of observation during many experiments, some made specifically for the purpose of observing the appearance and others for other purposes.

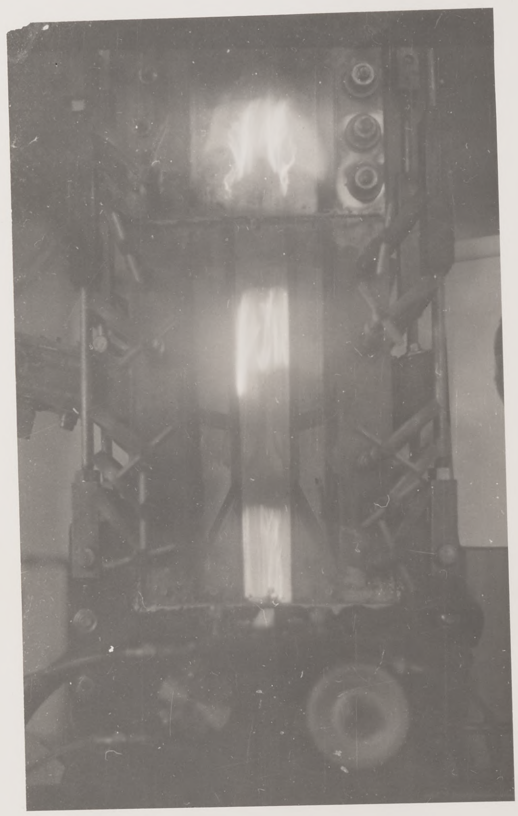


Figure 6b

Picture of Discharge taken with Focal Plane Shutter Camera. Scanning of the Object was from top to bottom.

The remarks made here on the appearance of the discharge have no chronological bearing to other experiments reported. They are the result of observation during many experiments, some made specifically for the purpose of observing the appearance and others for other purposes.

PRELIMINARY TESTS AND DATA

The first tests consisted of observations on the amount of spreading of the glow and of efforts to improve this distribution thereby decreasing the current density on the electrodes and the instantaneous ratio of power to gas in the discharge. On the assumption that conduction in the gas occurs simultaneously with the presence of glow and that a negligible percentage of the power is spent in the relatively dark space, photographs of the discharge were taken to determine the instantaneous conditions prevailing. As stated before, this type of observation has its defects. Other data consists of observations of the voltage wave shapes and measurements of gas flow and root mean square voltage across the discharge. These data are shown in Table IV and Figures 7 and 8 and agree qualitatively with data obtained by Howard and Kasperik[17] on an arrangement in which a blower electrode and a solid faced electrode were operated at speeds varying from zero to 2700 and zero to 2000 r.p.m., respectively. These tests showed that the r.m.s. voltage and the voltage wave shape changed with speed of rotation. Next to each point plotted in Figure 8 will be found one or two of the letters A, D, and T, which indicate the type of discharge that was obtained with the different conditions. A is for arc, D is for diffuse discharge, and T is for transition type discharge. Figure 7 shows the type of voltage wave obtained with each condition. This method of determining the type of discharge obtained depends very much on the personal factor. A different

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17 Howard, W. B. and Kasperik, A. S., Unpublished Report, Bureau of Industrial Chemistry, The University of Texas, May 20, 1943.

classification and a method of determining the type will be presented in the section on <u>Tests on Current Distribution Between Rotor and Plate Electrodes</u>.

Another test that was proposed was that of measuring the current being passed by different parts of the plate electrodes. Even though it was realized that a probe might not measure the conditions that existed before its introduction it was decided to place a current probe over a small part of the low potential plate electrode. The bottom part of a thin sheet iron strip one inch high and extending across the width of the low potential plate was placed three and five-eighths inches from the bottom of the plate. This probe was insulated from the plate and had a separate insulated lead. The following conditions and results were recorded for one test:

Total current = 6.2 amperes

Probe current = app. 1.5 amp. (fluctuating)

Voltage = 3200

Plate-to-plate distance = 5 inches

Gas rate = 43.9 cu.ft. per sec.

Height of discharge above top of probe = 2 to 3 inches

Rotor speed = 4500 r.p.m.

The current wave form obtained showed that the probe conducted only during a small part of the cycle and thereby indicated that conduction was not uniform over the entire surface. This test led to the idea that an observation of the rotor current wave and of the plate current wave might throw some light on the current distribution. It was found that during the first part of every half-cycle only the rotors would conduct and that during the next part only the plates would. Also it was found that under certain conditions the plates would cease conducting before the end of the half-cycle of circuit current and the rotors would

TABLE IV

Test no.	Gas rate cu.ft/sec.	Plate sep'n. inches	Voltage	Volts / plate sep'n.	Gas velocity between plates, ft/sec.
1	50.	5.	3600	720	240
2	43.5	5.	3400	680	209
3	37.	5.	3280	656	178
4	29.	5.	3040	608	139
5	16.7	5.	2000	400	80.2
6	46.	3.5	3320	949	316
7	37.	3.5	3080	880	254
8	29.	3.5	2720	777	199
9	16.7	3.5	1720	491	115
10	29.	2.	2520	1260	348
11	23.6	2.	2160	1080	284
12	16.7	2.	1840	920	201

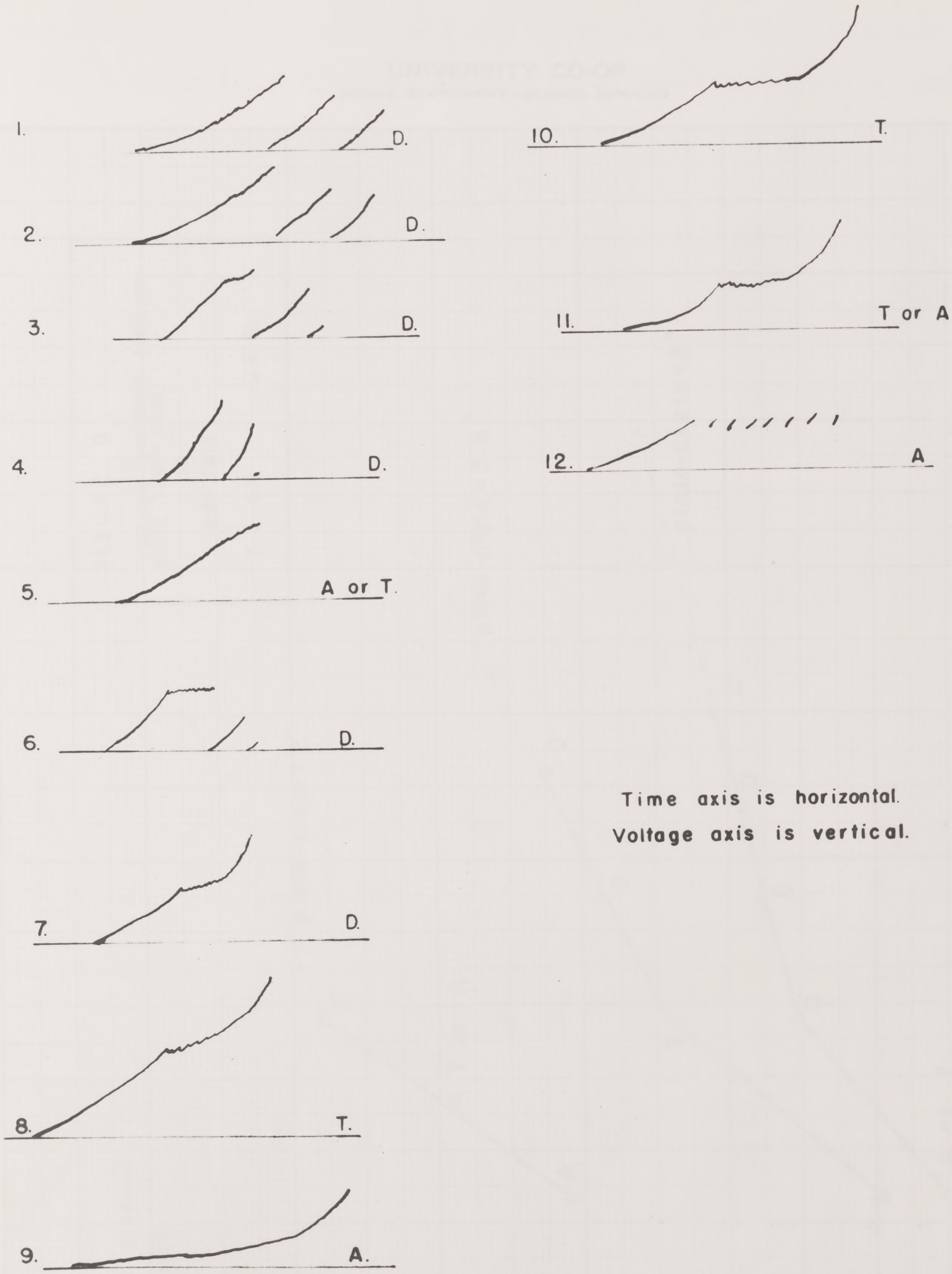

FIGURE 7
Voltage wave shapes

7-5-45 G.E.M.

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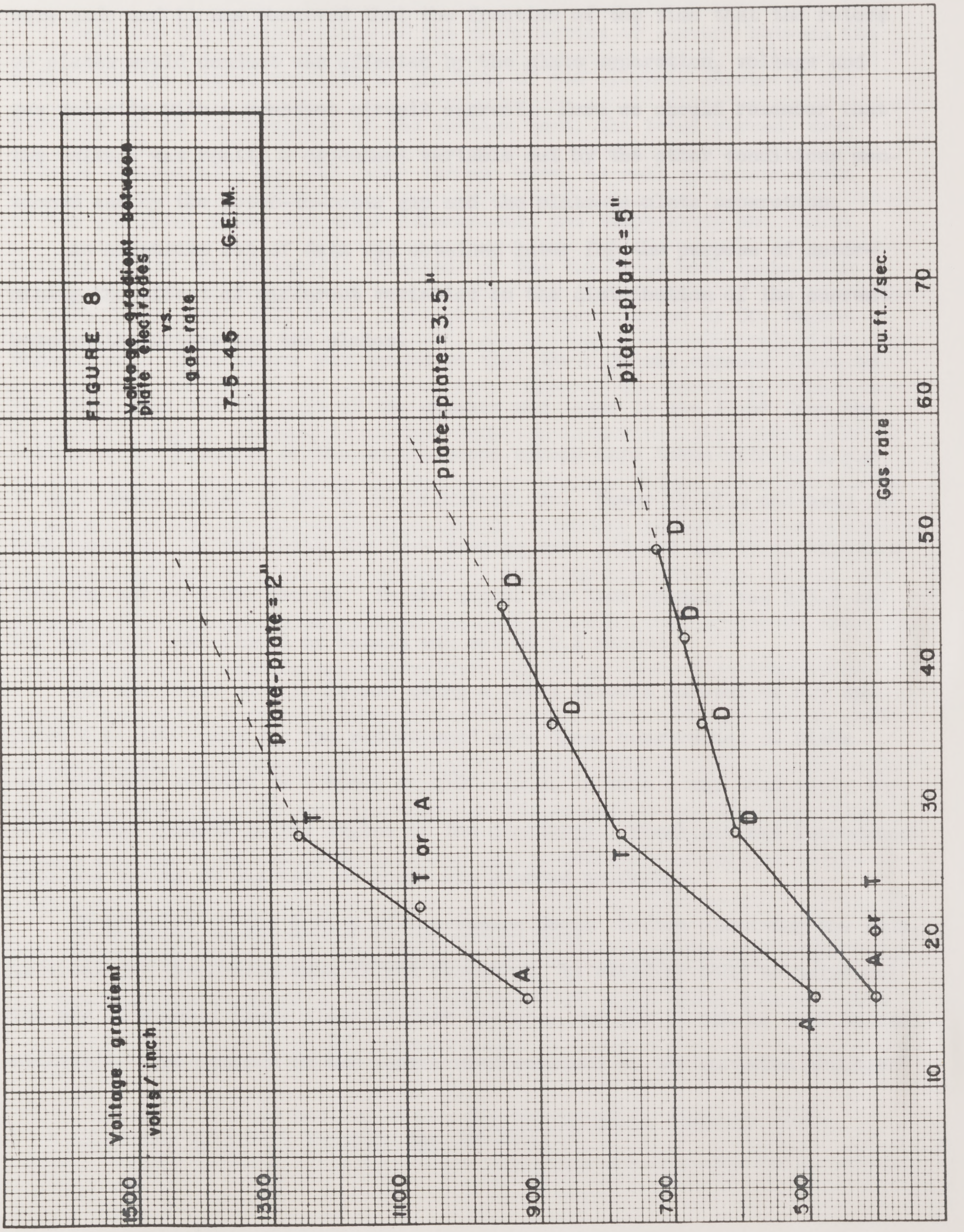

conduct again. In all cases, however, the total current had a sine wave form. No photographs of the current wave shapes were obtained but sketches were made and it was observed that the fraction of the time that the rotors or plates would conduct was affected by the plate separation, voltage and gas velocity with a constant circuit current. Here we should remember that the voltage was really a dependent variable set by the other conditions mentioned and by the rotor-to-rotor gap and the plate-to-plate separation.

An extensive set of data was obtained later for the purpose of determining the effect of different variables on the distribution of the current between the rotors and the plates.

TESTS ON CURRENT DISTRIBUTION BETWEEN

ROTOR AND PLATE ELECTRODES

Data for the determination of the distribution of current between the rotors and the plates consists of pictures of the electric discharge and pictures of the oscillograms of the voltage wave, the total current wave (always sinusoidal), and the rotor current wave, as well as measurements of the gas rate, plate and rotor separations, gas temperature and r.m.s. voltage across the discharge. Pictures of the discharge were taken with a Leica 35 mm., Type IIIB focal plane shutter camera loaned by Dr. Eugene Schoch, Jr. This camera was turned so that the film was exposed first to the light from the top part of the chamber and later to the light from the bottom part. Pictures of the oscilloscope screen were taken with an Argus 35 mm. camera loaned by Mr. R. P. Lightfoot, Jr. Super XX film was used in both cameras. In the Leica the lens opening was f/2 and the local exposure time was set at 0.001 second. In the Argus, the lens opening was f/3.5 and the exposure time (local or total) was set at 0.1 second.

All the tests were performed using a total circuit current of 6.1 amperes A.C. (60 c.p.s.). The rotors used were those constructed of disks only and were rotated at a speed of 4500 r.p.m. in such a way that their surfaces moved upwards in the region of the discharge. Fresh air was introduced into the system at the rate of about six hundred cu.ft/hr.

<u>An Analysis of the Action of the Camera Used</u>: Before examining the data, particularly the photographs of the discharge, it would be well to point out the way in which a focal plane shutter operates and how it can be used to best advantage. The shutter in the camera used consists of two curtains arranged

to move in the same direction and at the same speed, but timed so that in effect there is always a narrow slit between the trailing end of the first one and the leading end of the second one as they move in front of the film (the curtains are almost in the focal plane). As a result the film is not exposed all at the same time, and moving objects appear distorted in an amount and a manner depending on the relative velocity between the object and the opening in the shutter[18]. Thus, if the camera is placed so that as the shutter scans the scene from left to right, light from the left side of the chamber is admitted first and that from the right is admitted last, the discharge bands will slope upwards from left to right if they move relatively fast compared to the scanning action. On the other hand if the camera is turned so that the discharge chamber is scanned from top to bottom, the bands, instead of appearing as inverted U's, approach a rectangular shape. Also the number of bands appearing in the picture is greater than the number that actually exist at any one time. For example if at the time that the top part of the chamber is being scanned there is a discharge band at that place, it will appear on the film. At the same time there may be no other discharge bands present in any part of the chamber, but if by the time that the bottom part of the chamber is being scanned, a band is present there, that one will also appear on the film. If only one band can be present at any one time, the number seen in a photograph will depend on the relative velocities of the shutter and of the discharge bands.

<u>Determination of Band Velocities by the Band-to-Band Method:</u> This distortion has been utilized to measure the speed at which the discharge bands

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18 Mack, J. E. and Martin, M. J., <u>The Photographic Process</u>, 1939, McGraw Hill Book Company, pp. 138-141.

move up the chamber. The present method makes use of the fact that pictures of the discharge showed two or three discharge bands. If one assumes that at the time that the bottom part of the top band is being scanned, the entire band is about to disappear and that another band is just about to start on the rotors, one can find the average velocity at which the second band moves up the tube. To do so one must measure on the photographic negative the distance between the bottom part of the top band and top part of the next band. This gives a measure of the time required for scanning between the two points in question. Again, if one measures the distance from the top part of the second band to the plane determined by the axes of the rotors one knows how far the second band has travelled in the same time. This presupposes that the speed of scanning is known. The manufacturer of the camera informed us that the time for scanning the entire frame of film was about 0.025 seconds[19]. A check made by photographing a rotating disk with a bright spot on its surface gave a value of 0.0273 second to scan a distance of 36.5 mm. on the film. Figure 9a shows a disk with a spot near the periphery. The angle described by the spot is about 80° and the distance d scanned on the negative is 7.9 mm. To this distance of 7.9 mm. one should add a correction for the width of the slit since it is the leading edge of the slit which first "sees" the bright spot and it is the trailing edge which finally "loses sight" of it. In one of the pictures of the rotating disk, the streak produced by the bright spot appears at the bottom of the disk, so it was caught going in the direction opposite to that of the scanning action. The length of the streak on the corresponding photographic negative gives the width of the slit. This width is 2.4 mm., so the correct distance to be used is $7.9 + 2.4 = 10.3$

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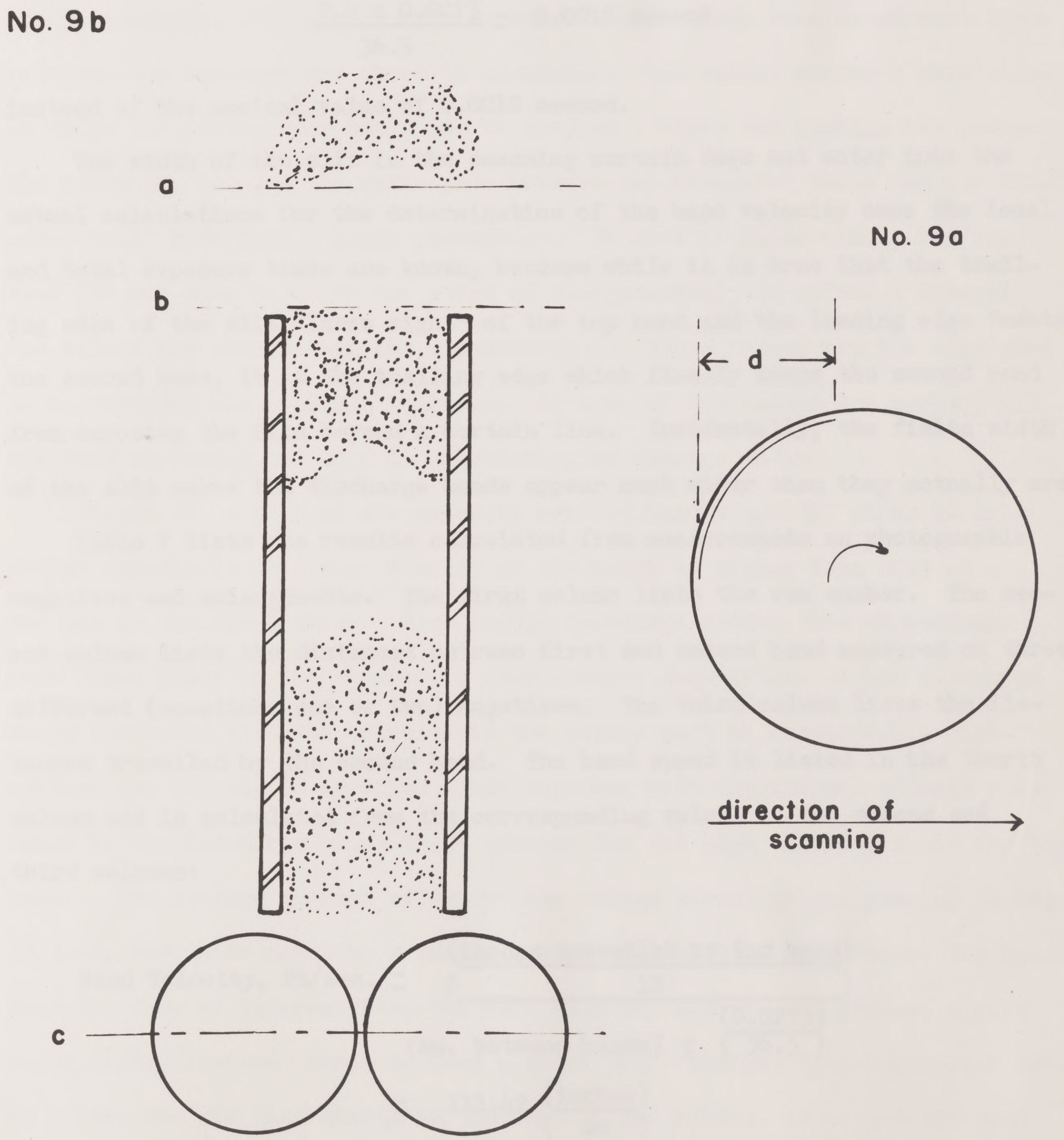
19 George V. Moran, E. Leitz, Inc. Private Communication, April, 1946.

FIGURE NO. 9



mm. The time to scan the entire frame is:

$$\frac{(60 \text{ sec./min.})\ (80^{\circ})\ (36.5 \text{ mm.})}{(1729 \text{ r.p.m.})\ (360^{\circ}/\text{rev.})\ (10.3 \text{ mm.})} = 0.0273 \text{ seconds}$$

This, incidentally, gives us the value of the local exposure:

$$\frac{2.4 \times 0.0273}{36.5} = 0.0018 \text{ second}$$

instead of the nominal value of 0.0010 second.

The width of the slit in the scanning curtain does not enter into the actual calculations for the determination of the band velocity once the local and total exposure times are known, because while it is true that the trailing edge of the slit "loses sight" of the top band and the leading edge "meets" the second band, it is the trailing edge which finally keeps the second band from exposing the film beyond a certain line. Incidentally, the finite width of the slit makes the discharge bands appear much wider than they actually are.

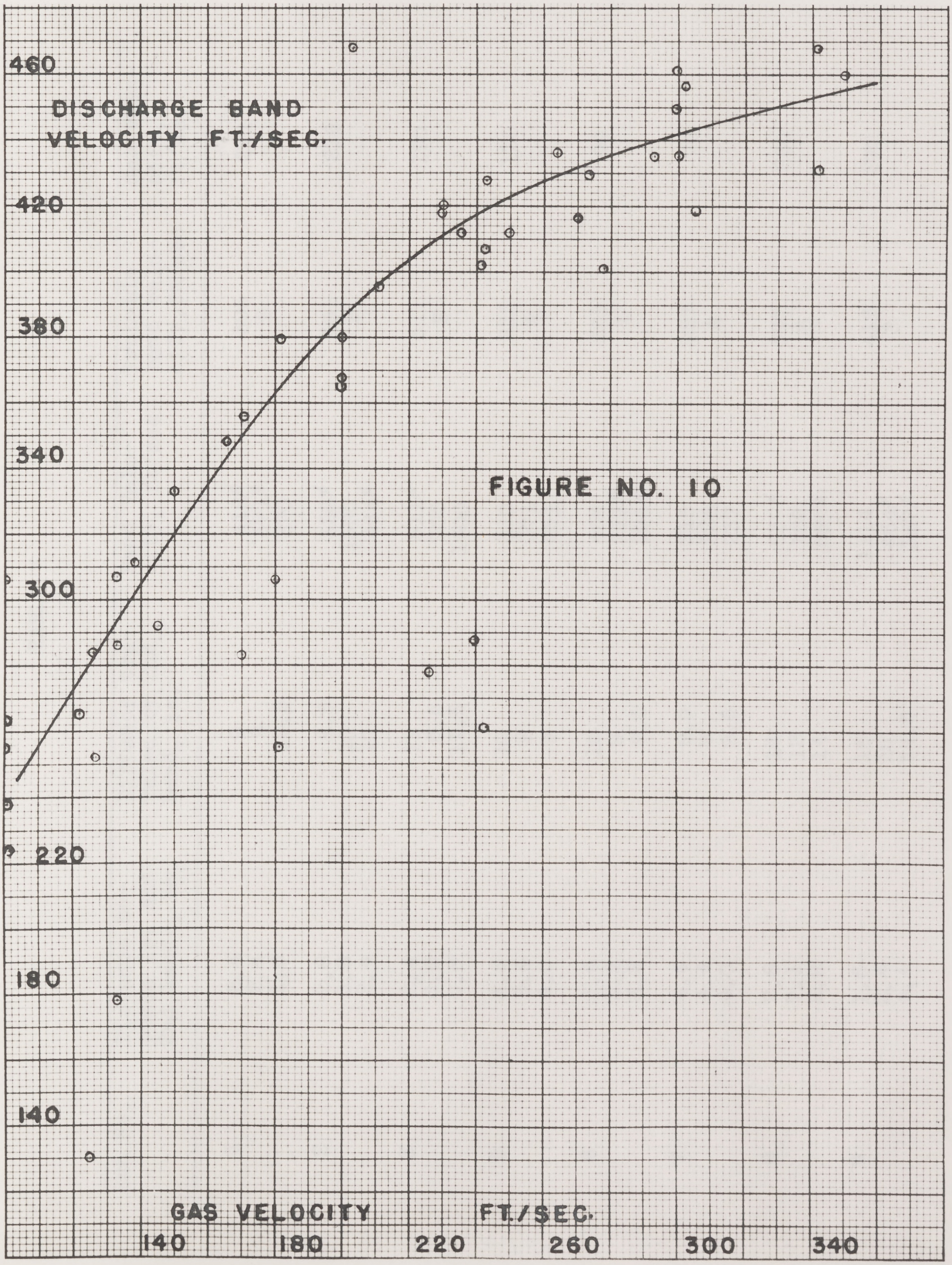
Table V lists the results calculated from measurements on photographic negatives and enlargements. The first column lists the run number. The second column lists the distances between first and second band measured on three different (sometimes one or two) negatives. The third column lists the distances travelled by the second band. The band speed is listed in the fourth column and is calculated from the corresponding values in the second and third columns:

$$\text{Band Velocity, ft/sec.} = \frac{\left(\dfrac{\text{inches travelled by 2nd band}}{12}\right)}{(\text{mm. between bands}) \times \left(\dfrac{0.0273}{36.5}\right)}$$

$$= 111.42 \frac{(\text{inches})}{(\text{mm})}$$

The fifth column lists the probably band velocity, which, as the name implies, is the value of velocity which is judged to be the true one. The basis for the choice is explained below. In the same column will be found the letter A or the letter B. Those numbers followed by an A are those values of probable velocity which were picked on the basis of the appearance of the photographs. The photographs on which these values were based were those in which the top band was about to disappear. The values marked B were those in which the photographs could not be used as a basis for picking the probable velocity, because the difference between the resultant value and the final curve would have been a large percentage. In most of these cases, the top band did not seem to be on the verge of disappearing. In column 4 some of the values are marked with the superscript ∅. These values are the ones used in calculating the probable velocity. If none of the values are marked, all the ones appearing are used in calculating an average value.

Figure 10, a plot of air velocity against band velocity, shows an apparent anomaly in that the velocity of the bands is higher than that of the gas in the range shown. Even though turbulent rather than streamline flow takes place in the chamber, a stroboscopic observation of the discharge bands indicates that the velocity in the center must be considerably higher than the calculated average. This together with the thermal effects produced in the discharge bands might account for the high velocity found for the bands. The average thermal effect on the entire amount of gas passing is negligible, but there might be a considerable local effect. Also since the bands take the form of inverted U's, the part half way between the plates, always being highly ionized, tends to form a short path, thereby "pulling itself up". In effect the gas that starts in the band at the rotors, is not in the band by the time that the band reaches the top of the plates. This, incidentally,



460
420
380
340
300
220
180
140
DISCHARGE BAND
VELOCITY FT./SEC.
FIGURE NO. 10
GAS VELOCITY FT./SEC.
140
180
220
260
300
340

TABLE V

Run No.	Distance between 1st and 2nd bands, mm.	Distance traveled by 2nd band, in.	Band Velocity, ft/sec	Probable band velocity, ft/sec	Gas Velocity, ft/sec
1	2.4	9	418ø	395	211
	2.4	8	371ø	B	
	1.6	12.5	870		
2	2.8	8.5	338ø	401	218
	0.8	10	1390	B	
	2.4	10	464ø		
3	2.4	11	511ø	511	190
	0.8	6.5	905	B	
	0.8	11.5	1600		
5	3.6	10	310	311	138
	2.4	8	371	A	
	4.0	9	251		
6	3.6	15	464	305	99
	3.2	9	313ø	A	
	3.2	8.5	296ø		
7	4.4	8.5	215	227	79
	4.4	9	228	A	
	4.0	8.5	237		
8	2.8	16	637ø	597	280
	7.1	12	188	B	
	2.8	14	557ø		
9	1.6	16	1114	416	270
	2.4	10	464ø	B	
	4.4	14.5	367ø		

TABLE V
(continued)

Run No.	Distance between 1st and 2nd bands, mm.	Distance traveled by 2nd band, in.	Band Velocity, ft/sec	Probable band velocity, ft/sec	Gas Velocity, ft/sec
10	2.0	11.5	641	418	230
	5.2	14	300	A	
	4.0	15	418ø		
11	4.4	12	304	380	182
	4.0	15	418	A	
	3.2	12	418		
12	4.4	13	329	284	126
	4.8	11	255	B	
	4.8	11.5	267		
13	0.8	5	696	255	100
	0.8	6	836	B	
	4.8	11	255ø		
14	4.0	16	446	431	342
	4.8	18.5	429	A	
	4.0	15	418		
15	4.4	18.5	468	461	300
	3.6	16.5	511	A	
	4.4	16	405		
16	4.8	17	394ø	420	230
	4.0	16	446ø	A	
	3.6	12	371		
17	2.8	8.5	338	500	167
	1.2	6.5	604	A	
	1.2	6.0	557		

TABLE V
(continued)

Run No.	Distance between 1st and 2nd bands, mm.	Distance traveled by 2nd band, in.	Band Velocity, ft/sec.	Probable band velocity, ft/sec.	Gas Velocity, ft/sec.
18	3.6	8.5	263	286	133
	3.2	11	383ø	A	
	4.4	7.5	190ø		
19	3.6	14	433	386	385
	4.8	16	371	A	
	5.2	18	386ø		
20	2.8	16	637	435	293
	3.6	15	464ø	B	
	4.4	16	405ø		
21	4.4	10	253	380	200
	3.2	16	557	A	
	4.4	15	380ø		
22	2.8	8.5	338	428	243
	3.2	16	557	B	
	4.0	14	390		
23	4.4	8.5	215	261	243
	3.6	10	310	A	
	6.4	15	261ø		
24	5.6	13.5	269	283	170
	5.6	11	219	A	
	4.0	13	362		
25	5.2	12.5	268	292	145
	4.4	12.5	317	A	

TABLE V
(continued)

Run No.	Distance between 1st and 2nd bands, mm.	Distance traveled by 2nd band, in.	Band Velocity, ft/sec.	Probable band velocity, ft/sec.	Gas Velocity, ft/sec.
27	3.6	8.5	263ø	263	100
	4.0	5	139	A	
	3.6	8.5	263ø		
28	4.4	8.5	215ø	233	84
	4.0	9	251ø	A	
	1.2	10	929		
29	3.6	15	464	430	274
	3.2	16.5	574	A	
	4.4	17	430ø		
30	5.6	15.5	308	412	236
	3.6	16.5	511	A	
	4.4	16.5	418		
31	2.8	18	716	656	187
	2.4	15	696	B	
	3.6	18	557		
32	4.8	13	325	307	133
	4.4	12.5	317	A	
	4.8	12	279		
33	4.4	10	253	237	98
	4.8	9.5	221	A	
34	3.2	16	557	460	350
	4.0	13	362	A	
	4.0	16.5	460		

TABLE V
(continued)

Run No.	Distance between 1st and 2nd bands, mm.	Distance traveled by 2nd band, in.	Band Velocity, ft/sec.	Probable band velocity, ft/sec.	Gas Velocity, ft/sec.
35	4.4	16.5	418	418	305
	4.4	13	329	A	
	4.4	2.0	506		
36	3.6	20.5	634	522	233
	3.2	15	522ø	B	
	3.2	13.5	470		
37	3.2	8.5	296	306	180
	2.0	5.5	306	A	
	4.0	11	306ø		
38	4.0	10.5	292ø	265	122
	4.0	10	279	A	
	4.0	8.5	237ø		
39	4.4	14	355	484	360
	4.8	17	395ø	A	
	3.6	18.5	573ø		
40	3.6	16.5	511ø	436	264
	4.0	18	501	A	
	4.8	15.5	360ø		
41	7.1	3.5	55	365	200
	3.2	11	383ø	A	
	4.8	15	348ø		
42	2.4	16	743	550	375
	5.2	18	386ø	A	
	3.2	20.5	714ø		

TABLE V
(continued)

Run No.	Distance between 1st and 2nd bands, mm.	Distance traveled by 2nd band, in.	Band Velocity, ft/sec.	Probable band velocity, ft/sec.	Gas Velocity, ft/sec.
43	4.0	18	501	456	302
	3.2	17	592	A	
	6.7	16.5	274		
44	6.0	15.5	288ø	288	240
	12.4	8	72	A	
	7.5	10	149		
45	4.8	12	279ø	279	226
	6.4	9.5	165	A	
	2.0	4.5	251		
46	3.6	12	371	435	300
	3.2	13	453ø	A	
	4.8	18	418ø		
47	3.2	15.5	540	552	380
	2.8	16	637	A	
	3.6	15.5	480		
48	4.4	20	506	468	342
	4.8	19	441	A	
	4.4	18	456		
49	3.2	16	557	503	302
	4.8	20	464ø	A	
	3.6	17.5	542ø		
50	4.4	16.5	418ø	412	250
	2.8	14	557	A	
	4.8	17.5	406ø		

TABLE V
(continued)

Run No.	Distance between 1st and 2nd bands, mm.	Distance traveled by 2nd band, in.	Band Velocity, ft/sec.	Probable band velocity, ft/sec.	Gas Velocity, ft/sec.
51	3.6	11.5	356	356 A	171
52	2.4	10	464	348 A	166
	4.0	12.5	348ø		
	2.4	7.5	348		
53	7.1	10.5	165	178 A	133
	7.1	10	157		
	7.5	12	178ø		
54	3.2	15	522	495 A	334
	4.0	20	557ø		
	4.0	15.5	432ø		
55	5.2	21	450ø	450 A	300
	3.2	20	696		
	3.2	14.5	505		
56	4.0	17.5	487ø	402 A	242
	5.6	15	298		
	5.6	16	318		
57	6.0	12.5	232ø	255 A	181
	6.7	9	150		
	4.8	12	278ø		
58	7.5	8	119	130 A	125
	7.9	10	141		

TABLE V
(continued)

Run No.	Distance between 1st and 2nd bands, mm.	Distance traveled by 2nd band, in.	Band Velocity, ft/sec.	Probable band velocity, ft/sec.	Gas Velocity, ft/sec.
59	3.6	18	557ø	557	280
	4.0	20	557ø	A	
	3.2	14.5	505		
60	5.2	19	407ø	407	243
	3.6	16	495	A	
	3.2	16	557		
61	2.4	10	464	367	200
	2.8	13	517	A	
	4.4	14.5	367ø		
62	2.4	5.5	255	333	150
	2.4	7.5	348	A	
	2.8	10	398		
63	4.8	10	232ø	224	102
	0.8	5	696	A	
	4.4	8.5	215ø		
64	4.4	19	481	468	203
	4.4	18	456	A	

is very desirable, for the oftener the gas in the band is replaced, the lower is the ratio of power to gas. It is this ratio rather than the ratio of power spent to total gas going through the chamber that is important.

Determination of Band Velocity by Oscillogram Method: The above method of determining band velocities may be called the band-to-band method. The following method may be called the oscillogram method. By means of the oscillogram of the rotor or plate current waves, one can determine how long the plates conduct, and by means of photographs of the discharge one can determine the highest distance that any band moves up the plates. From these figures, the band velocity can be calculated. For example if the oscillogram shows that the plates conduct for ninety electrical degrees (0.00416 second) and the discharge moves twelve inches on the plates, the band velocity is 1.0/0.00416 = 240 ft/sec. Table VI shows the results obtained by this method. The results are not plotted against gas velocity because the points determined do not fall on or near any curve, although there is fair agreement in many individual cases between the results given by the oscillogram method and those given by the band-to-band method. The reason for the wide discrepancies found is that the distances that had to be measured were even smaller than those encountered in the first method. On the photographic print one cycle occupies about one inch; so one thirty-second of an inch represents about eleven electrical degrees. This same distance is approximately the width of the electron beam trace; so an error of ten to fifteen degrees (ten to seventy-five per cent) is not unlikely.

Other Methods of Determining Band Velocities: Two other methods of measuring band velocities suggest themselves. One is a photographic method in which a focal plane shutter camera is turned so as to scan the field from one side to the other. Knowing the speed of scanning and measuring the slope of

TABLE VI

Run	Average Time on plates (nearest 5°)	App. distance travelled by band, in.	Band Velocity ft/sec	Gas Velocity ft/sec
1	20	11	986	211
2	30	11	659	218
5	20	13	1165	138
6	35	11	567	99
7	90	11	220	79
9	90	18	360	270
10	65	18	498	230
11	70	16	411	182
12	85	9	191	126
13	100	9	162	100
14	85	21	445	342
15	110	21	344	300
16	100	19	342	230
17	105	14	240	167
18	105	14	240	133
19	60	21	630	385
20	125	18	259	293
21	105	15	257	200
22	65	20	554	243
23	60	20	600	243
24	65	17	471	170
25	55	16	524	145
27	45	12	480	100
28	40	8	360	84

TABLE VI
(continued)

Run	Average Time on plates (nearest 5°)	App. distance travelled by band, in.	Band Velocity ft/sec	Gas Velocity ft/sec
29	110	21	344	274
30	105	21	360	236
31	80	17	383	187
32	90	15	300	133
33	90	11	220	98
34	85	20	424	350
35	100	20	360	305
36	110	17	278	233
37	105	15	257	180
38	105	13	223	122
39	95	22	417	360
40	115	19	297	264
41	110	22	360	200
42	105	23	394	375
43	115	21	329	302
44	120	23	345	240
45	80	17	383	226
46	105	21	360	300
47	105	20	343	380
48	115	23	360	342
49	95	23	436	302
50	120	21	315	250
51	100	15	270	171
52	105	15	257	166

TABLE VI
(continued)

Run	Average Time on plates (nearest 5°)	App. distance travelled by band, in.	Band Velocity ft/sec	Gas Velocity ft/sec
53	95	21	398	133
54	105	23	394	334
55	105	23	394	300
56	105	20	343	242
57	110	13	213	181
58	110	18	295	125
59	80	23	518	280
60	90	20	400	243
61	100	18	324	200
62	105	14	240	150
63	75	12	288	102
64	120	22	330	203

the discharge bands, one can calculate the velocity. The few pictures taken to test out this method indicate that other factors tend to make the bands appear sloped and that at times the slope is such as to yield a negative value for the band velocity. The other method is a combination optical and electrical method. Two vacuum photoelectric cells can be placed in a vertical line so as to receive light from a relatively small part of the chamber. The electrical impulses resulting from the light of the discharge after being amplified can be put on an oscillograph. If the sweep circuit frequency is known and the distance between the lines indicating substantial changes of light is measured, the band velocity can be calculated. This method was not tried at all.

Discharge Types: In examining the voltage and current oscillograms, it was found that they could be classified according to the way in which the current divided itself between the rotors and the plates. With a given electrode arrangement and no separate control of the currents, the current distribution may be according to one of the following types: (1) only rotors conduct, (2) current starts on rotors at beginning of every half-cycle and later transfers to the plates, ceasing to pass between the rotors, (3) same as in (2), except that plate current stops before end of half cycle and rotors start to conduct again, (4) rotors conduct twice and plates conduct twice during half-cycle, (5) rotors conduct three times and plates conduct twice during the half-cycle. Sketches of the average wave forms are shown in Figure 11, and Table VII includes a column showing the kind of discharge found for each set of conditions. In this set of data there are no instances of type 1 or 4, but previous experiments have shown that type 1 can be brought about by a combination of low gas rate and sufficiently low rotor speed. Probably the only reason that type 4 was not obtained is that the range of gas rates favorable to the presence of this type is very narrow and was not investigated.

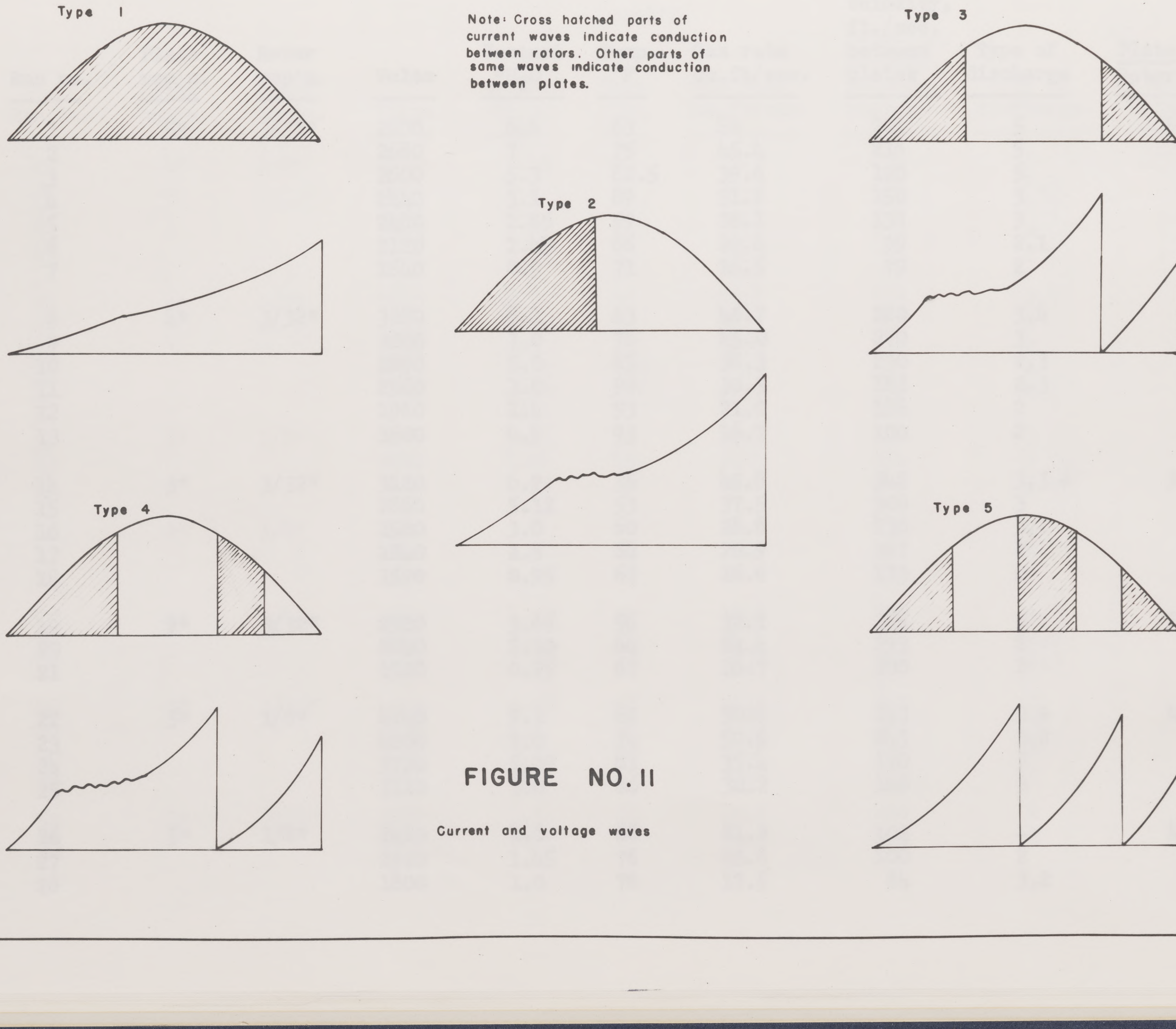


FIGURE NO. II

Current and voltage waves

TABLE VII

Run no.	Plate sep'n.	Rotor sep'n.	Volts	Venturi "H_2O	Temp. ^oF	Gas rate cu.ft/sec.	Velocity, ft./sec. between plates	Type of discharge	Plate sep'n. / Rotor sep'n.
1	5"	3/32"	2800	8.6	63	44	211	5	53.3
2			2680	7	75	45.4	218	5	"
3			2600	5.3	82.5	39.6	190	5	"
4			2440	3.1	89	31.2	150	3	"
5			2480	2.85	59	28.7	138	3	"
6			2120	1.45	66	20.6	99	2,1	"
7			1640	0.9	71	16.5	79	2	"
8	4"	3/32"	3280	8.1	63	46.7	280	3,4	42.7
9			3200	7.0	78	45.0	270	3	"
10			2880	5.0	85	38.3	230	2,3	"
11			2560	3.0	90	30.3	182	2,3	"
12			1960	1.4	93	21.0	126	2	"
13			1600	0.9	93	16.7	100	2	"
14	3"	3/32"	3120	6.9	35	42.8	342	3,3 +	32
15			2880	5.12	53	37.5	300	3	"
16			2560	3.0	60	28.8	230	3,2	"
17			1840	1.5	64	20.9	167	2	"
18			1520	0.95	67	16.6	133	2	"
19	2"	3/32"	2520	3.65	56	32.1	385	3	21.3
20			2040	2.10	64	24.4	293	2	"
21			1520	0.95	67	16.7	200	2	"
22	5"	1/8"	4240	9.1	62	50.6	243	3 +	40
23			4000	7.0	74	50.6	243	3,2	"
24			3720	5.07	81	35.4	170	3	"
25			3120	3.0	86	30.2	145	3	"
26	5"	1/8"	2480	1.6	62	21.2	102	-	40
27			2520	1.45	76	20.8	100	2	"
28			1800	1.0	78	17.5	84	3,2	"

TABLE VII

cont'd.

Run no.	Plate sep'n.	Rotor sep'n.	Volts	Venturi "H_2O	Temp. ^oF	Gas rate cu.ft/sec.	Velocity, ft./sec. between plates	Type of discharge	Plate sep'n. / Rotor sep'n.
29	4"	1/8"	3880	7.45	66	45.7	274	3	32
30			3480	5.3	76	39.3	236	2,3	"
31			3000	3.2	83	31.2	187	2,3	"
32			2240	1.6	86	22.2	133	2	"
33			1560	0.85	87	16.3	98	2	"
34	3"	1/8"	3240	6.2	70	43.8	350	2,3	24
35			3000	4.9	78	38.1	305	3	"
36			2480	2.8	83	29.1	233	2	"
37			2040	1.65	85	22.5	180	2	"
38			1200	0.75	85	15.3	122	2	"
39	2"	1/8"	2800	3.6	34	30.0	360	3	16
40			2000	1.8	45	22.0	264	2	"
41			1800	0.98	49	16.7	200	2	"
42	2"	1/4"	3400	3.5	60	31.2	375	3	8
43			2800	2.2	65	25.2	302	2,3	"
44			2800	1.35	68	20.0	240	2	"
45	2"	3/16"	2640	1.17	72	18.8	226	2,3	10.7
46			2640	2.1	75	25	300	2,3	"
47			3440	3.35	77	31.7	380	2,3	"
48	3"	3/16"	4000	6.25	69	42.8	342	3	16
49			3520	4.8	76	37.8	302	3	"
50			3000	3.2	80	31.3	250	2	"
51			2080	1.5	81	21.4	171	2	"
52	3"	3/16"	2080	1.5	58	20.8	166	2	16
53			1680	0.95	63	16.7	133	2	"

TABLE VII

cont'd.

Run no.	Plate sep'n.	Rotor sep'n.	Volts	Venturi "H_2O	Temp. °F	Gas rate cu.ft/sec.	Velocity, ft./sec. between plates	Type of discharge	Plate sep'n. / Rotor sep'n.
54	3"	7/32"	4000	6.1	70	41.8	334	3	13.7
55			3600	4.8	77	37.5	300	3	"
56			3000	3.1	80	30.3	242	2	"
57			2320	1.7	82	22.6	181	2	"
58			1840	0.8	83	15.6	125	2	"
59	4"	5/32"	4080	7.7	72	46.7	280	3	25.6
60			3880	5.7	83	40.5	243	3	"
61			3280	3.6	88	33.3	200	2	"
62			2640	2.0	88	25.0	150	2	"
63			1640	0.95	89	17.0	102	2	"
64			4040	3.75	89	33.8	203	2	"

[20] Cobine, J. D., Gaseous Conductors, McGraw Hill Book Company, 1941, pp. 194-195.

It might be pointed out that with oscillograms of only two or three half-cycles one can assign only an integral number to the type of discharge. However, if for each combination of gas rate, rotor gap and plate separation tested, oscillograms of several half-cycles were available, one would find that one half-cycle may show a discharge to be type three, for example, and the next half-cycle may show it to be type four, since every half-cycle in a discharge is different due to the random manner in which breakdown occurs[20]. By studying enough half-cycles, one could assign a number between three and four, say three and six-tenths, to the discharge in question. The advantage would be that it would facilitate the study of the factors that bring about one type of discharge or another, because the type number could be plotted against any of the variables investigated.

Significance of Discharge Type and of Band Velocity: The reader might wonder why so much emphasis is placed on discharge type and on the velocity of the discharge bands. These two factors might determine how efficiently a given discharge may bring about chemical change. On the premise that to obtain efficient chemical transformation, there should be a high ratio of gas to expenditure of power, the following analysis is made. Type 1 discharge is one that stays on the rotors all the time while the gas passes between the rotors. One might reason that since the discharge stays in a limited region and the gas passes through, the ratio of gas to power is large and efficiency may be high. However, type 1 results only when the gas rate is low; so it is impossible to attain the condition desired. Type 2 differs from No. 1 in that the discharge is transferred to the plates and continues there until the end

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[20] Cobine, J. D., Gaseous Conductors, McGraw Hill Book Company, 1941, pp. 194-195.

of the half-cycle. In type 3, since the current again starts on the rotors before the end of the half-cycle, the power is spent in two separate discharge bands, thereby giving a higher ratio of gas to power with a consequent increase of efficiency. By the same reasoning, the higher the type of discharge, the better the efficiency to be expected. This theory is partly supported by the fact that Howard and Kasperik[21] have obtained higher efficiencies with discharges which resembled types 4 and 5 than with those resembling types 2 or 1. As shown, before the discharge bands may move as fast, or faster, than the gas, but if there is much turbulence the result is a mixing of the gas with a removal of ions and energy from the main body of the band and the addition of unionized gas to this discharge region. These effects all add up to give the equivalent of a high ratio of gas to power. Another effect that would be produced would be that of bringing about a higher voltage drop across the chamber due to the partial deionization of the band[22,23]. This would increase the capacity of a given chamber.

Table VIII serves to describe the current waves obtained. The values listed are the times in electrical degrees (0 to 180°) at which current ceases to pass between rotors or plates, as the case may be. The values for runs 1 and 2 are listed separately for convenience because these two runs yielded type 5 discharges.

		End of conduction on				
Run	Type	Rotor	Plate	Rotor	Plate	Rotor
1	5	55°	75	130	150	180
2	5	60	90	120	150	180

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[21] Howard, W. B., and Kasperik, A. S., Unpublished Data of Bureau of Industrial Chemistry, The University of Texas, (Runs ME 113-136,) 1943.

[22] Maxfield, F. A. and Benedict, R. R., Theory of Gaseous Conduction and Electronics, McGraw Hill, 1941, pp. 368-379.

[23] Dow, W. G., Fundamentals of Engineering Electronics, John Wiley and and Sons, Inc., New York, 1937, p. 434.

TABLE VIII

Run No.	Discharge Type	Conduction stops at time indicated in degrees. Rotor	Plate	Rotor
5	3	135	155	180
6	1,2	145-180	180	
7	2	90	180	
8	3	---	---	---
9	3	40-60	120-160	180
10	2,3	60-90	120-160	180
11	2,3	100	160-180	180
12	2	75-120	180	
13	2	70-90	180	
14	3,3+	40-60	120-150	180
15	3	30-65	160	180
16	2,3	60-85	170-180	180
17	2	60-90	180	
18	2	60-90	180	
19	3	40-80	120	180
20	2	40-70	180	
21	2	60-90	180	
22	3,3+	75-120	160-170	180
23	2,3	80-90	110-180	180
24	3	70-90	130-160	180
25	3	90-120	150-170	180
27	2	120-150	180	
28	2	120-160	180	
29	3	40-80	150-160	

TABLE VIII
(continued)

Run No.	Discharge Type	Conduction stops at time indicated in degrees: Rotor	Plate	Rotor
30	2,3	40-90	160-180	180
31	2,3	80-90	150-180	180
32	2	60-120	180	
33	2	80-100	180	
34	2,3	40-90	120-180	180
35	3	60-90	165-180	180
36	2	60-80	180	
37	2	60-90	180	
38	2	60-90	180	
39	3	40-90	150-165	180
40	2	40-90	180	
41	2	50-90	180	
42	3	40-80	160-170	180
43	2,3	40-80	170-180	180
44	2	60	180	
45	2,3	90	165-180	180
46	2,3	60-80	170-180	180
47	3	40-80	160-170	180
48	3	30-80	150-170	180
49	3	60-80	160-170	
50	2	60	180	
51	2	80	180	
52	2	60-90	180	
53	2	80-90	180	

TABLE VIII
(continued)

Run No.	Discharge Type	Conduction stops at time indicated in degrees: Rotor	Plate	Rotor
54	3	40-80	160-170	180
55	3	40-80	160-170	180
56	2	60-90	180	
57	2	60-80	180	
58	2	60-80	180	
59	3	80-90	160-170	180
60	3	60-90	170	180
61	2	60-100	180	
62	2	60-90	180	
63	2	90-120	180	
64	2	60	180	

CHANGES IN THE APPARATUS

In order to study further the possibility of obtaining a discharge in which a large amount of power could be spent efficiently, it was decided to construct another apparatus in which the plate electrodes would be about five feet long and in which current to the plates and the rotors could be controlled separately. It was felt that in such an arrangement the rotors would supply the plates with ionized gas and that there might be a possibility of obtaining a diffuse discharge between the plates. One point against this possibility is the fact that to get a diffuse discharge there would probably have to be two or more parallel discharges between the plates. Steinmetz[24] shows that it is impossible to maintain two parallel *arcs* without a certain minimum amount of separate stabilization. Any two or more discharge paths between the plates would be lacking separate stabilization, but would not necessarily correspond to the case taken up by Steinmetz.[25] The two *arcs* cannot coexist because of their negative current voltage characteristic, but a diffuse discharge may have a positive dynamic volt-ampere characteristic at least during part of the time. By properly timing the introduction of ionized gas from the region between the rotors, there would be a slight chance of maintaining two discharge bands between the plates, although in most cases the conductivity of one band would be increasing while that of the other would be decreasing, with the end result that this time for coexistence would be limited. Another question to be answered by the use of this chamber would be whether a discharge band after having been introduced between the plates

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[24] Steinmetz, C. P. *Theory and Calculation of Electric Circuits.* McGraw Hill Company, New York, 1917, pp. 175-180.

[25] Steinmetz, C. P., *Ibid.*

would continue conducting until it was blown off the ends of the plates.

With separate current controls for the plates and for the rotors, there can be a difference of voltage between the high potential plate and the rotor, and to prevent the formation of a discharge between them, bakelite insulation was used to replace part of the chamber wall near the bottom of the plate. As a further deterrent to the formation of this discharge, the distance between the high potential plate and the rotor was changed from one-half inch to about three inches. This, however, proved to be too large a distance to permit the transfer of the discharge from the rotors to the plates; so the plate was returned to its original position.

It was also decided to use resistance controlled direct current at least for the first tests on this longer chamber. The cource of d.c. power is a General Electric Thyratron rectifier Model 6RP16A1, with some modifications. The original design[26] called for type FG-118 thyratron tubes while at present type FG-41 tubes are being used. The starting characteristics are different for the two types. The original design also called for a three phase 63 KVA, 220 to 7410 volts transformer and in this investigation three 75 KVA, 2300 to 6900 volts transformers were used in delta-delta connection. The output voltage with currents up to at least ten amperes remained at 9200 volts. Currents up to about 25 amperes are available with this arrangement.

Other changes or additions included the installation of suitable banks of resistors for the separate control of the rotor and plate currents; the speeding up of the gas booster to approximately 4300 r.p.m.; the installation of the proper electrical metering circuit; and a slight modification of the rotor electrodes. The rotors were changed so as to consist of eleven

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[26] General Electric Company, Instructions G.E.I. 18299, Schenectady, New York, 1935.

evenly spaced disks, giving an electrode width of four and one-half inches.

Figure 12 shows the electrical metering circuit, and Figure 13 shows a view of the new chamber.

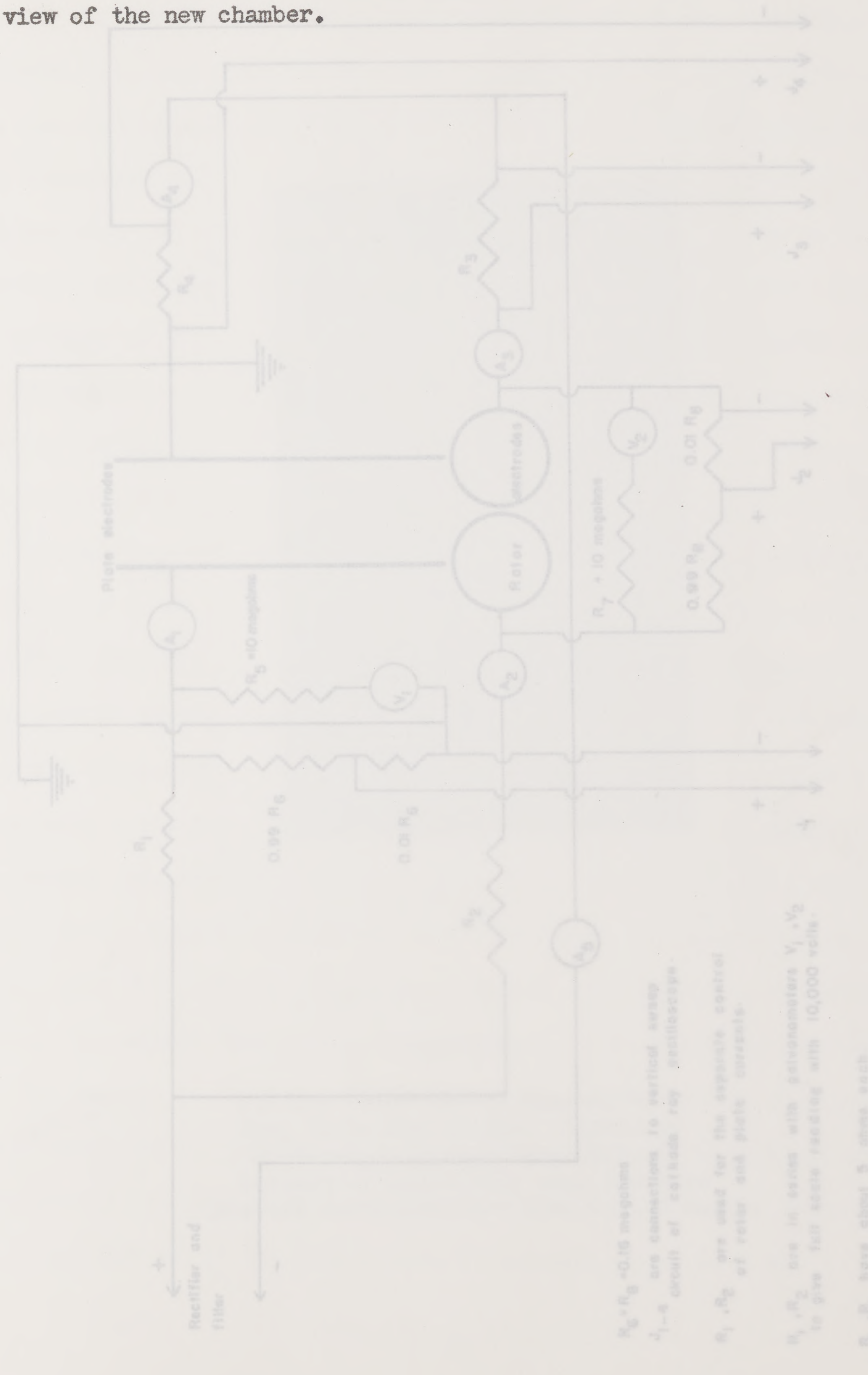
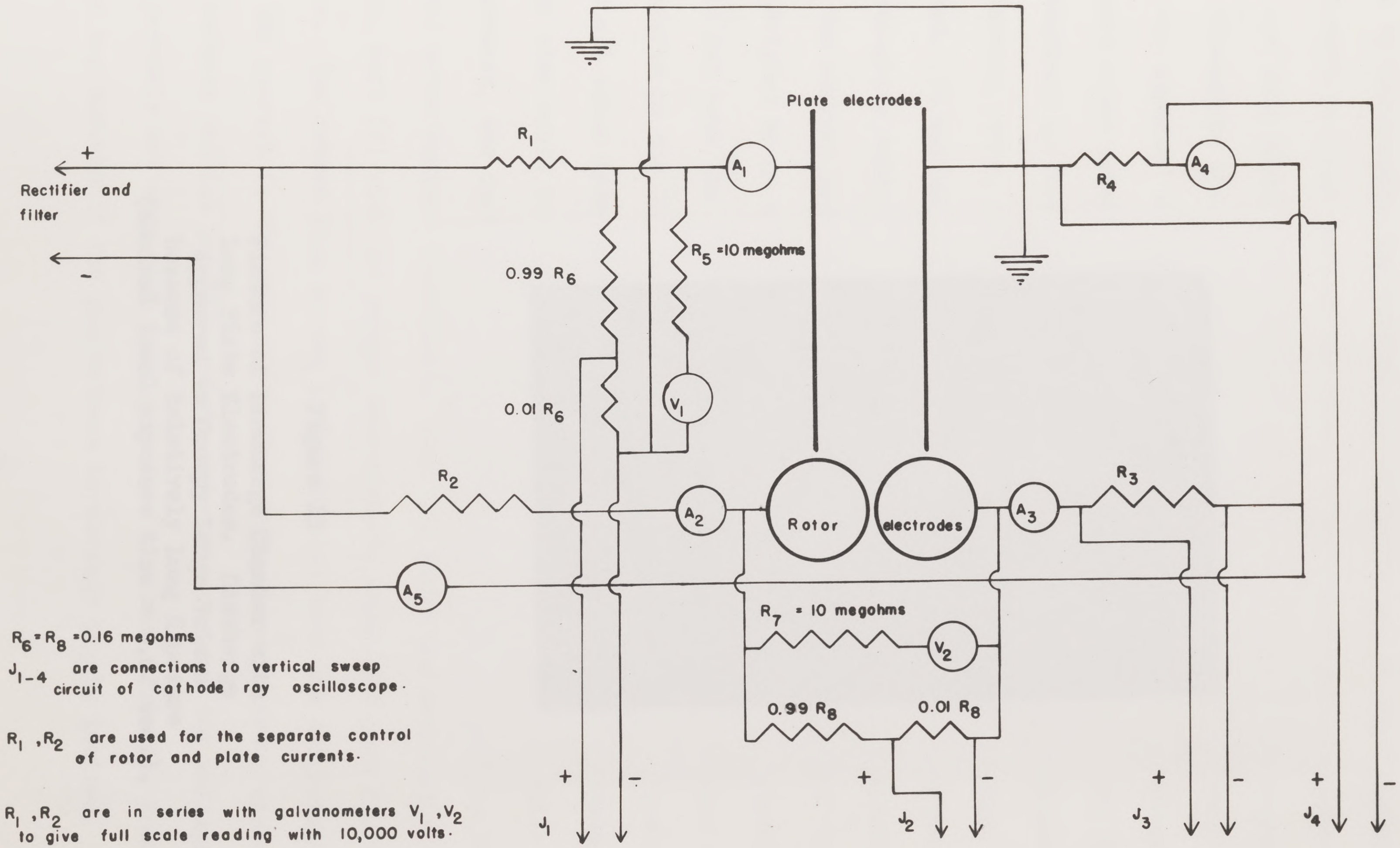


FIGURE NO. 12



$R_6 = R_8 = 0.16$ megohms

J_{1-4} are connections to vertical sweep circuit of cathode ray oscilloscope.

R_1, R_2 are used for the separate control of rotor and plate currents.

R_1, R_2 are in series with galvanometers V_1, V_2 to give full scale reading with 10,000 volts.

R_3, R_4 have about 5 ohms each.

A_{1-5} : ammeters

FIGURE NO. 12

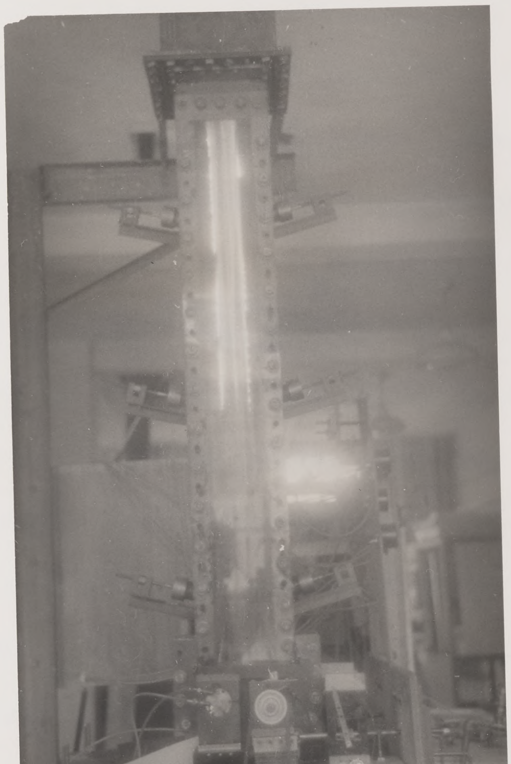
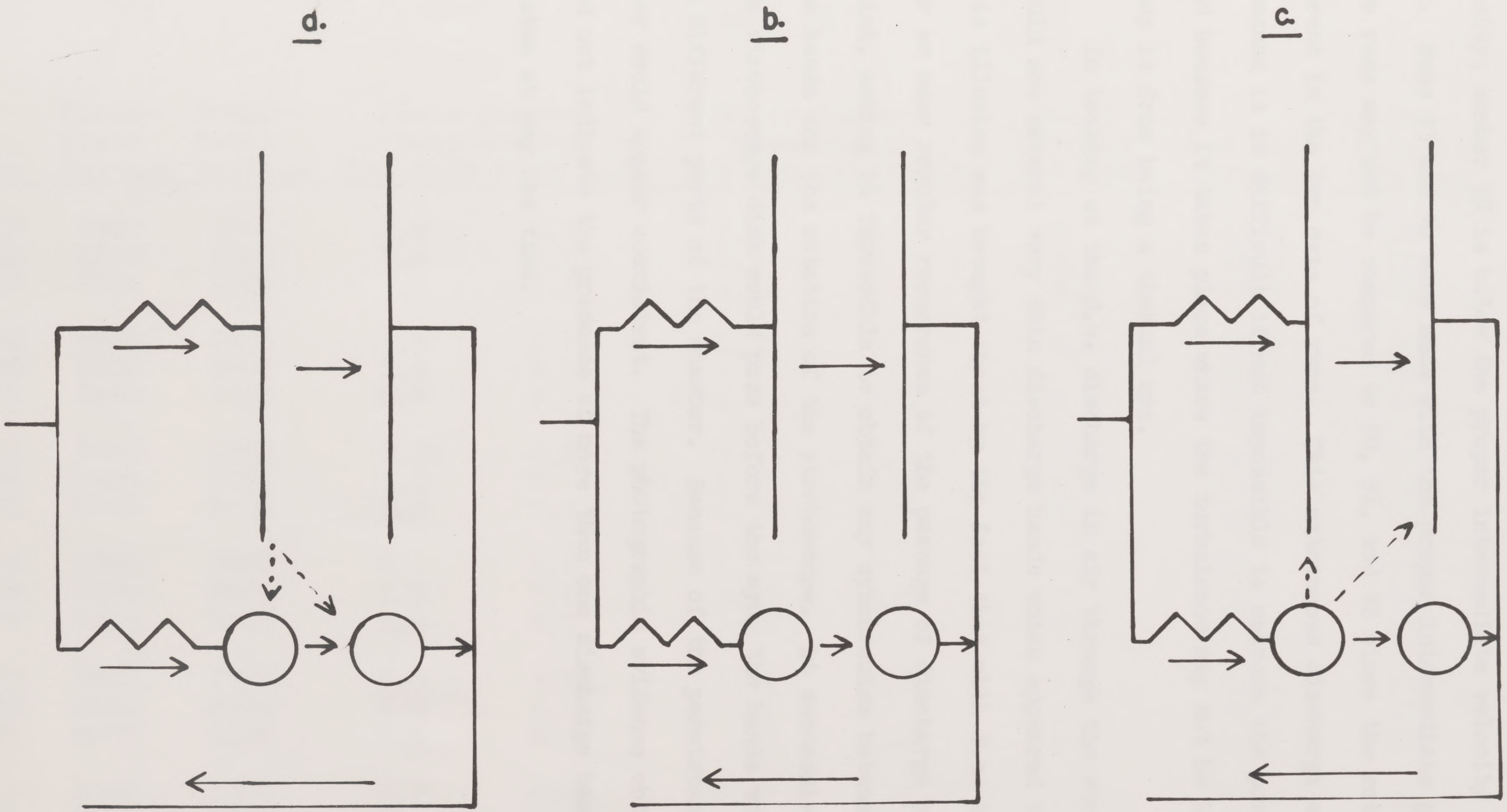


Figure 13

Picture of Discharge Chamber with
Long Plate Electrodes. Discharge
Appeared to Occupy Large Volume
because of Relatively Long Exposure
(nominal local exposure time = 0.02 sec.).

TESTS WITH DIRECT CURRENT

The main purpose of the first tests with direct current (runs 65-105) was to investigate the possibility of having two or more discharge bands coexistent at least part of the time. A secondary and more general purpose was to see what complications might arise from having the two separately stabilized discharges (rotor-to-rotor and plate-to-plate) close to each other. While it was expected that the amount of power spent in the discharge between the rotors might affect the resistance of the other discharge and there might be a tendency to form a discharge between the high potential plate and the high potential rotor, the exact action of this extraneous discharge was not anticipated. It was natural to expect that the difference in the rotor-rotor and plate-plate voltages would be an important factor in determining the direction of the current between the rotor and plate. However, it was found that it was outweighed by an unexpected factor, the gas rate. It was found that at a certain gas rate the value of the plate current would be the same whether it was measured on the high side or on the low side. Then if the gas rate increased and all other independent variables remained constant, the value read on the high side would be higher than that read on the low side, while if the gas rate decreased, the converse would be true. Figure 14 illustrates the action encountered under various conditions. Part (a) shows the currents with a high gas rate, part (b) with the proper intermediate rate, and part (c) with a low gas rate. The dotted line arrows in (a) and (c) show the two possible paths taken by the current in the extraneous discharge. No extraneous discharge is indicated between the low potential plate and rotor because the voltage between them is probably not more than twenty to thirty volts. This is, however, enough to pass any current if the gas between is already highly ionized.



Solid arrows indicate known paths of current.
Dashed arrows show paths which can exist
together or alone and give the same effect.

FIGURE NO. 14

Runs 98 and 99, Table IX, show the effect brought about by changing gas velocity; number 99 is below the proper intermediate velocity and 98 is above it. Runs 93 and 94 were made with the proper intermediate gas rate. These two runs may not be compared to 90, 91, and 92 since the rotor gap was different in the two sets of runs. This extraneous discharge should be avoided because it is difficult if not impossible to measure the power spent in it and because it takes place where the turbulence may not be high enough to keep it from being a thermal arc.

In looking at the d.c. discharge in air through the stroboscope one could see several very thin discharge bands which appeared to be coexistent. This illusion was brought about by the fact that with d.c. there is no regular or near regular recurrence of the passage of discharge bands past any point, making it impossible to obtain any synchronism between the motion of the bands and the rotation of the stroboscope. At successive openings in the stroboscope disk would pass before the eye, the bands would be caught in different parts of the chamber. Because of the persistence of the image, they would appear coexistent. The photographic evidence obtained, however, did not indicate the presence of more than one discharge band between the plates at any one time.

TABLE IX

Run	Plate-Plate Voltage	Rotor-Rotor Voltage	Plate Current Measurement Low Side	Plate Current Measurement High Side	Rotor Current Measurement Low Side	Rotor Current Measurement High Side	Total Current Low Side	Gas Rate cuft/sec	Gas Velocity ft/sec
65	2400	1500	3.5	5.0	1.4	3	7	43.8	350
66	2800	2600	2.0	5.0	1.2	4	6.5	43.8	350
67	2200	3000	1.5	5.5	1.15	5	6.5	36.9	295
68	2300	3000	1.4	5.5	1.15	5	6.5	36.9	295
69	2400	3000	1.6	5.5				36.9	295
70	2600	2400	2.3	7	1.2	5.5	8	43.7	350
71	2600	2800	2.25	6.5	1.1	6.0	7.5	40.5	324
72	2400	3000	1.6	7	1.1	7.0	8.0	33	264
73	2400	3000	1.3	7.5	1.15	7.5	8.5	24.4	195
74	2600	2600	2	6.5	1.2	5	7.5	43	344
75	2400	3000	1.5	7.0	1.15	6.5	8	33	264
76	2200	3000	1.2	7.0	1.15	7	8.5	23.4	187
77	2600	3200	3.5	4.0	1.15	1.3	5.0	21.6	173
78	3500	3500	2.5	2.5	.75	1	3	29.5	236
79	6000	4000	1.5	2.0	.45	.8	2	28.1	225
80	3000	1400	2.5	2.75	0.6	1.0	3.05	23.4	281
81	2600	1500	2.5	3	0.6	1.0	3.4	19.55	235
82	2400	2000	3	3	0.6	0.7	3.5	14.75	177
83	2400	3000	3	3	0.5	0.7	3.5	14.75	118
84	2800	2800	2.5	3	.5	1	3.4	19.15	153
85	3200	2400	2.25	2.75	0.525	1	3.4	22.15	177
86	3000	2000	2	3	0.575	1.6	3.4	23.4	187
87	3000	1700	1.5	2.75	0.6	2	3.3	27.6	221
88	2200	2800	2.5	3.0	.5	1.4	3.5	14.75	89

TABLE IX
(continued)

Run	Plate-Plate Voltage	Rotor-Rotor Voltage	Plate Current Measurement Low Side	Plate Current Measurement High Side	Rotor Current Measurement Low Side	Rotor Current Measurement High Side	Total Current Low Side	Gas Rate cuft/sec	Gas Velocity ft/sec
89	2600	2500	2	3	0.5	1.5	3.5	18.8	113
90	4000	1400	1	2	.6	2	3	21.9	131
91	3800	2300	1	2.5	.55	2	3.4	22.75	137
92	3000	2000	2	2.5	.6	1.4	3.0	24.4	195
93	3500	3400	2.5	2.5	.9	1	3.2	29.5	236
94	3400	3500	2.5	2.5	.9	1	3.25	23.4	187
95	3000	3400	3.0	2.52	.87	.6	3.5	19.9	159
96	2800	2500	2	3	1.05	2	3.6	34.7	416
97	2800	2500	2	3	1.05	2	3.6	34.7	416
98	2400	2400	2.5	3	1.05	1.5	3.8	23.4	281
99	2200	2500	3.4	3	1.05	1	4	18.1	217
100	2500	3000	2.5	3	1	2	3.8	18.8	113
101	7500	3500	0	.5	.9	1.5	1.5	54.2	325
102	6000	3000	.3	.75	.9	1.8	1.5	46.7	280
103	6000	3000	.5	1.5	0.9	1.8	2.5	40.5	243
104	3000	4800	1	3	1.0	3	3.7	23.8	143
105	2800	2800	2	3	1.0	2	3.7	24.4	146

DETERMINATION OF VOLUME OF SYSTEM AND AMOUNT OF LEAKS

The volume of the system was determined by adding enough air to bring the pressure to about four to six inches of mercury and then allowing the excess air to pass out through a meter until some lower pressure was attained. By extrapolation of the gas volume bled out to zero absolute pressure, the volume of the system may be found. During the time of letting out the air through the meter, some of it leaks out at a rate dependent on the prevailing pressure. The amount that leaks out should be added as a correction to the first value of the volume. However, the method used here for finding the rate of leakage presupposes a knowledge of the volume of the chamber. Accordingly with the data obtained one can find an approximate value of the volume and then determine the amount of leaks and add this value to the uncorrected volume. A second approximation is unnecessary.

Only enough data to demonstrate the method are shown here. Table X shows the data used primarily for the volume determination, and leakage reported is based on the equation: (Leakage, cu.ft/min.) = 0.032 x (system pressure, "Hg)

From Table X,

$$\text{Volume of system} = \text{Barometric pressure} \times \frac{(40-29)}{(5.62-1.35)} = 29.13 \frac{(11)}{(4.27)} = 75.042$$

This figure is the basis for the last column of Table XI. The last two columns of Table XI are plotted against each other together with other similar data, they yield the equation:

(Leakage, cu.ft/min.) = 0.032 (System press., "Hg)

The correct value for the volume of the system is 75.042 + 0.956 = 75.998. The average of three determinations is 76.08 cu.ft.

TABLE X

Meter reading cu.ft	Avg. press. during determination "Hg	Increment of time, min.	Leak during operation cu.ft
29		0	
30	5.34	0.68	0.116
31	4.88	0.74	0.116
32	4.48	0.66	0.095
33	4.20	0.75	0.101
34	3.85	0.75	0.092
35	3.35	0.85	0.091
36	2.95	0.90	0.084
37	2.60	0.92	0.077
38	2.23	0.95	0.068
39	1.82	0.98	0.057
40	1.50	1.22	0.059
			0.956

Pressure at start = 5.62
Pressure at end = 1.35

Table XI has data that deals primarily with the leakage determination.

TABLE XI

Pressure "Hg	Decrement of pressure "Hg	Increment of time min.	Leakage cu.ft./min.	Avg. pressure during leakage "Hg
3.45				
3.24	0.21	5.05	0.109	3.35
2.92	0.32	4.61	0.182	3.08
2.74	0.22	4.67	0.124	2.83
2.52	0.22	6.25	0.092	2.61
1.10	1.42	54.09	0.069	1.81

QUANTITATIVE TESTS ON THE CHEMICAL ACTION

OF THE DISCHARGE IN AIR

Because so many different observations need to be made during a test of the efficiency of the discharge, it was decided to make some tests on air and not risk damaging the electrical insulation until all conditions were properly planned.

The test was as follows: The inlet and outlet valves of the system were closed off. The system pressure and temperature were determined. The discharge was then turned on and kept on for a few minutes. The exact time that the discharge was kept on was recorded, together with the electrical meter readings. After the power was turned off a sample was taken, and the system pressure and temperature were taken again. The discharge was turned on again and the necessary observations were made.

When the discharge acts on air, oxides of nitrogen are produced. The products can be NO, NO_2, and N_2O_4. The formation of the last two, either directly or indirectly, through NO, accounts for the decrease of volume of gas in the system. The samples were analyzed for fixed nitrogen by the direct method of Haber and Koenig.[27] This method consists of adding an excess of hydrogen peroxide solution to the sample and allowing the nitrogen oxides to be changed to nitric acid, the amount of which is then determined by titration with N/20 barium hydroxide. The production of HNO_3 per KWH shown for the second power increment is the increase in the amount of fixed nitrogen, expressed in terms of HNO_3, divided by the amount of power required to bring about this increase. The production of oxides (HNO_3) is reported on two bases:

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[27] Haber, F. and Koenig, A., Über die Stickoxydbildung Im Hochspannungbogen. Z. Elektrochem. 46, 725, (1907).

(1) neglecting effect of gas leaks, (2) considering effect of gas leaks. In the second case, it is assumed that the composition of the gas that leaks out during the run is half way between the composition of the gas at the beginning of the run and that at the end.

The efficiency of HNO_3 production is low compared to values of about 80g.HNO_3/KWH obtained by Haber and Koenig.[28] However, in our case, relatively large amounts of oxides may have reacted with the metal surfaces.

Table XII shows the data and results of this test.

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28 Haber, F. and Koenig, A., Ibid.

TABLE XII

	Sample TD1	Sample TD2
Plate-plate voltage	2700v	2600
Rotor-rotor voltage	2700v	2600
Plate current, high side	5.5 amp.	5.5
Plate current, low side	4.5	4.5
Rotor current, high side	1.0	1.0
Rotor current, low side	2.0	2.0
Total current, low side	6.5	6.5
Power based on low side	17.55KW	16.9
Time for discharge, sec.	300	300
Total energy	1.463KWH	1.408
% NO_2	0.216	0.297
Average temp. of system before	82°F	99°F
Average temp. of system after	99°F	103
System press. before	0"H_2O	-2.4
System press. after	-2.4	-3.2
Gas rate	34.3 cu.ft/sec.	33.1
Barometer	746.0 mm.	
Chamber press. during run	0.7"Hg	0.45
Plate spacing	3"	
Rotor speed	4500 r.p.m.	
Volume before power input	67.237 cu.ft.	65.192
Volume after power input	65.192 cu.ft.	64.729
Difference in volumes	2.045 cu.ft.	0.463
Calculated leaks	0.112 cu.ft.	0.072
Grams HNO_3(equivalent) before power input	0	9.435
Grams HNO_3(equivalent) after power input	9.435	12.822
Grams HNO_3/KWH	6.45	2.406
Grams HNO_3/KWH corrected for leaks	6.46	2.407

TESTS ON NATURAL GAS

During the last test on air an insulator failed. In looking for the insulator in question it became necessary to open the chamber and look inside. After the chamber was closed again, a test for leaks was performed. Using natural gas, the test gave the result:

(Leakage, cu.ft./min.) = .065 ("Hg)

In the first test on natural gas, the discharge between the rotors was steady, but that between the plates was intermittent. The electrical meters also showed that practically no current (not even in substantial surges) was passing from one plate to the other, and that a discharge of about six amperes took place between the high plate and the high rotor. Contrary to what had been found in the tests on air, it was impossible to control this extraneous discharge by varying the gas rate or the rotor-rotor separation.

Since it was not possible to maintain a steady discharge between the plates, it was decided to make some efficiency determinations using the rotors only. Two of the sets of runs made are reported here. The samples were analyzed for acetylene on a Fisher Burell laboratory apparatus. The acetylene was absorbed in alkaline $K_2Hg\ I_4$, which also absorbs CO_2. Howard[29] describes an empirical method based on analyses of samples for CO, by which the correct per cent acetylene may be obtained. This method, however, is not applicable to samples containing as low as three per cent acetylene. A conservative way of arriving at a value for the acetylene content is to subtract the CO_2 content found in the blank from the sum of CO_2 and C_2H_2 contents in the sample. This is conservative for two reasons. The first is

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[29] Howard, W. B. op. cit.

that some of the CO_2 is converted to CO and possibly other compounds. The second reason is that there is an increase of volume and even if none of the CO_2 were converted, the per cent CO_2 in the sample would be less than that in the blank. At the relatively low power inputs used in these tests neither of the factors mentioned is very important.

The method of calculating one step continuous data from batch data is the one developed and described by the writer.[30]

Table XIII is a summary of the data and results of runs TD 7-9 and TD 10-12.

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30 Montes, G. E., op. cit.

TABLE VIII

Runs TD 7-9
Power data:
Run

TD 7: (2 min.) (1.2kv) (4.8 amp.)/60 = 0.192 KWH
8: (4) (1.2) (4.9)/60 = 0.392
9: (6) (1.2) (4.9)/60 = 0.588

Gas Analyses (Volume per cent):

Sample	$CO_2 + C_2H_2$	C_2H_2
TD 7a	2.10	0
7	2.91	0.81
8	4.01	1.91
9	5.74	3.64

Runs TD 10-12
Power data:
Run

TD 10: (2) (1.2) (4.8)/60 = 0.192 KWH
11: (4) (1.35) (4.7)/60 = 0.423 KWH
12: (6) (1.4) (4.7)/60 = 0.658 KWH

Gas Analyses:

Sample	$CO_2 + C_2H_2$	C_2H_2
TD 10a	0.34	0
10	1.10	0.76
11	2.60	2.26
12	4.78	4.44

TABLE XIII Cont'd.

Volumetric and Yield Data

Run No.	7	8	9
Gas in chamber before power input	67.13	66.71	66.38
C_2H_2 in chamber before power input	0	0.5404	1.2679
Gas in chamber after p.i. and venting	66.71	66.38	66.03
C_2H_2 in chamber after p.i. and venting	0.5404	1.2679	2.4035
C_2H_2 leaked during power input	0.0013	0.0022	0.0049
C_2H_2 leaked during sampling	0.0013	0.0213	0.0213
Gas vented	1.60	2.98	4.41
C_2H_2 vented	0.0064	0.0805	0.1226
C_2H_2 in chamber + outside after p.i.*	0.5494	1.3210	2.5523
C_2H_2 produced	0.5494	0.7806	1.2844
C_2H_2 produced/KWH	2.86	1.99	2.18
Linear avg. vol. % C_2H_2 during p.i.	0.4	1.36	2.78

All volumes given are in cubic feet measured at 0^oC and 760 mm. Hg.

*- C_2H_2 outside means that which leaked out during the run in question + that leaked during sampling + that vented. All volumes are corrected to N.T.P.

TABLE XIII

Volumetric and Yield Data

Run No.	10	11	12
Gas in chamber before power input	67.07	66.77	66.55
C_2H_2 in chamber before power input	0	0.5075	1.5040
Gas in chamber after p.i.	66.77	66.55	66.12
C_2H_2 in chamber after p.i.	0.5075	1.5040	2.9357
C_2H_2 leaked during p.i.	0.0009	0.0058	0.0216
C_2H_2 leaked during sampling	0.0003	0.0012	0.0024
Gas vented	1.87	2.69	3.98
C_2H_2 vented	0.0142	0.0608	0.1767
C_2H_2 in chamber + outside after p.i.	0.5229	1.5718	3.1364
C_2H_2 produced	0.5229	1.0643	1.6324
C_2H_2 produced/KWH	2.72	2.52	2.48
Linear avg. vol. % C_2H_2 during p.i.	0.38	1.5	3.34

Other tests were made, but the efficiency of acetylene production found did not differ much from the values reported in Table XIII. Since these values are lower than those obtained with other electrode arrangements, the question arose as to why these low values were found even though the mean gas velocity in the region of the discharge was at least as high as that obtained with blower electrodes. The probability is that the disks in the rotors acted as straightening vanes and since the discharge took the shape of sheets in the planes determined by the disks, the gas went past the discharge bands, but not through the bands. The regions between and above the disks were the regions of intense discharge and low gas velocity.

DISCUSSION OF RESULTS AND POSSIBLE

IMPROVEMENTS ON APPARATUS

The low efficiency resulting from the use of rotors with disks only, while not foreseen, is clear and understandable in retrospect. As has been stated already, the most intense discharge took place in the regions through which the least amount of gas passed. Most of the gas that by-passed the discharge might as well have by-passed the entire chamber. These results, together with those obtained earlier in this investigation, point the way to some electric discharge devices which may have very desirable features.

Before considering any particular arrangement, one should consider the general principles that apply and the results obtained during this investigation. The main factors to consider are that: (1) the discharge seems to take the form of bands or streaks having cross sections which are small compared to the surface area of the electrodes used; (2) the velocity of the discharge bands as they move upwards may be higher than the average gas velocity between the plates; (3) there is some control over the frequency with which the discharge bands may be initiated.

Even though the discharge bands have small cross sections and contain only a small part of the gas that is between the electrodes, a low ratio of power to gas actually entering the discharge region can be obtained if the turbulence is high enough to bring about an entire replacement of the gas in the band several times during the existence of that band. Anything that brings about a great deal of turbulence without reducing unduly the gas velocity at certain places will be beneficial. Bringing the plates closer together will increase the velocity between these plates and also bring about a great deal of turbulence beyond the ends of the plates, due to the sudden expansion. However, there is also a sudden drop in average velocity; so the band tends to cling to the ends of the plate electrodes and to give a low voltage discharge. A low voltage brought about by some condition of gas rate rather than by a small electrode gap is indicative of a concentrated discharge.

Figure 10 shows that in the range of gas velocity of about 100-200 ft./sec., the band velocity may be twice that of the average gas velocity. If the correct conclusion has been drawn and the band velocity can actually be higher than the average gas velocity, the discharge bands must sweep through the gas, giving a low ratio of power to gas. The data at hand has not yet indicated why the band velocity can be higher or that incorrect conclusions have been drawn.

The discussion on discharge types shows why the frequency with which discharge bands are initiated is a factor in determining the ratio of power to gas actually passing through the discharge. In short, the higher the frequency of band initiation and extinction, the greater the number of bands for a given volume of gas and lower the ratio of power to gas actually contacted. In this connection, it is necessary to emphasize again and again that only the gas that is actually contacted by the relatively small discharge bands may be considered in arriving at the ratio of power to gas, and that this ratio depends more on the electrode arrangement and the method of directing the streams of gas than on the gas rate through the discharge chamber.

With these points in mind, one can consider some of the discharge devices that should be tried. While the action of these devices can be predicted partly, experiments are necessary to point out the less obvious advantages and disadvantages and to test out their action on a quantitative basis.

One promising design is that using two rotor electrodes such as the ones that are mentioned in the description of the apparatus originally designed for this investigation. Since such rotors tend to impede the gas flow, by forming a constriction in the discharge chamber, the gas that passes between the rotors can be accelerated to a high velocity which will tend to increase and equalize the specific electrical resistance at all points along the line of nearest approach of the rotors to such a high value that any lack of parallelism between the rotors will not easily concentrate the discharge near one end or the other. The rotors will converge the gas into a jet without adding much to its turbulence, but if their diameters are sufficiently small, much turbulence will be brought about in the low pressure side due to the relatively rapid divergence and to the introduction of extra gas through the openings of the rotors. This turbulence, as stated before, will help remove ions and energy from the discharge band and introduce unionized gas and will also help to extinguish the existing discharge band. Once a band is extinguished, a new one starts in another place, thereby increasing the ratio of gas actually contacted to the power spent. Within limits, the smaller the diameter of the rotors the sooner the bands are extinguished, and the more frequently new bands are initiated. These rotors probably do not need to attain a peripheral velocity equal to the gas velocity.

Another promising arrangement is that of using one rotating electrode against a stationary plate electrode. If this electrode is very short the discharge bands may be extinguished before they travel very far. The number of bands that appear and disappear may be such as to give a very high ratio of effective gas volume to power. On the other hand if the plate is long enough to let the discharge go up as far as other conditions will permit each discharge band lasts for a longer time but also will take in more gas. While these effects can be predicted qualitatively, it will be necessary to determine experimentally the optimum length of the electrode plate.

In either of these cases high gas velocities can be obtained with relatively low gas rates through the discharge chamber. Thus it may be possible to reduce the amount of gas that has to be passed through a chamber for a given power input to a value much smaller than the one required now. Also since the individual chambers do not have blower electrodes, the pressure required for moving the gas through the chambers may be obtained from a gas well with little or no expediture of power.

Another arrangement is one in which the discharge is initiated by rotors of some type and the main discharge takes place between plate electrodes. At least one of these plates should be covered with some material having a high specific electrical resistance so that when the discharge band is conducting between a given spot on one electrode and a spot on the other one, the voltage between the plates at other points will be higher than the voltage from one end of the band to the other, thereby bringing about a tendency to make the discharge band increase in volume or to initiate a new band at some new spot. Either way the ratio of power to gas contacted will be decreased. One material that has the desirable electrical characteristics and can be made into small plates is a mixture of carbon and clay, properly fired. A disadvantage of this arrangement may be the disintegration of this material due to the action of the discharge.

Another arrangement is one in which the discharge is initiated by rotors, but most of the power is spent between plate electrodes which are made into several electrically independent parts. In this way several simultaneous and separately stabilized discharges may be obtained. In connection with this arrangement and the one using the high resistance plate, it might be stated that while the rotors made of disks only did not initiate a steady discharge between the plates, rotors which also have blades may easily bring about the desired condition.

Combinations of these arrangements may be used, and may give very good results, but will undoubtedly complicate the analysis of the action.

SUMMARY

1. An apparatus for use in the study of the electric discharge in gases is described.

2. The possible advantages and disadvantages of the particular design are set forth.

3. A description of the electric discharge obtained is given.

4. Preliminary tests and results are described. These results showed that the discharge took place in relatively narrow bands or streaks.

5. A study of the factors influencing the motion of the bands is reported. Methods of determining the velocity of translation of the bands are described, and results found by two methods are given.

6. The development of a classification of the types of electric discharges obtainable is presented.

7. Changes made in the experimental apparatus are described.

8. Results of tests made on the separate stabilization of two discharges are presented.

9. Tests on the action of the discharge on air and on natural gas are presented and a discussion of the results is given.

10. Topics for further investigation are given.

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